PSYCHOLOGY OF TIME

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Chapter 12

Timing and Remembering the Past, the Present, and the Future

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> "Only those animals which perceive time remember, and the organ whereby they perceive time is also that whereby they remember."
> Aristotle (McKeon, 1941, pp. 607–608)

Although Aristotle scoffed at the idea that the brain carried out faculties such as timing and remembering (Williams, 2004), his statement is prescient. Modern researchers in the multidisciplinary field of cognitive science have revealed some of the processes by which humans and other animals remember events and represent time, including various time-related aspects of remembered events and episodes in their lives. Timing and remembering are two crucial functions without which animals would not be optimally adapted to changing environmental conditions. Specifically, encoding and remembering temporal information enable animals optimally to time actions in response to environmental events. They encode and remember the temporal order of events and the duration of episodes, including approximately when a past event occurred and how long a past episode lasted. Remembering the approximate recency of past events and the approximate duration of past and ongoing episodes helps guide future actions, which include the execution of plans for previously formed intentions.

In humans the interplay between timing and remembering is reflected in various ways. In some cases, timing plays the major role, and remembering is a necessary supportive system. In other cases, remembering plays the major role, and timing is a necessary supportive system. In all cases, however, adequate remembering is a necessary, although not a sufficient condition, for optimal performance. Timing as the main process with remembering as a supportive process is exemplified by autobiographical memory for past events and also by retrospective duration

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judgments. In these two examples, the goal is to remember when a past event occurred or how long an episode took to occur, and in both cases these tasks cannot be accomplished without the use of memory systems.

Evidence that people can remember the approximate duration of an episode (series of related events) comes from two kinds of paradigms. These reveal effects of different variables and seem to require different models (Block, 1990; Block & Zakay, 1997). One is prospective duration timing, which may be called *experienced duration*; and the other is retrospective duration timing, which may be called *remembered duration*. In prospective timing, a person is aware during a duration that he or she must estimate it. This may result from an experimenter's instructions or from everyday relevance and importance of timing. Prospective timing mainly depends on variables that influence the amount of attention a person devotes to time itself (see Block, 2003, for a recent review). On the other hand, in retrospective timing, a person is aware only after a target duration has ended that he or she must estimate it (see also Chapters 2 and 4).

In this chapter, we focus on research and theories concerning the major ways in which timing is linked with remembering: (a) timing the past, focusing on how people estimate the temporal location, or recency, of a past event, and how they estimate the duration of an episode retrospectively; (b) timing the present, focusing on how people estimate the duration of an episode prospectively (while it is in progress); and (c) timing the future, or how people execute a plan to perform an action at a specific future time.

We begin, however, by reviewing some historical and current models that may suggest similarities in the processes underlying timing the past, timing the present, and timing the future.

12.1. Historical and Current Models

Theorists have proposed various models concerning the encoding and remembering of temporal information. We critically and selectively review several important models, using a historical (chronological) organization. We begin with the older, simpler models in order to illustrate the evidence for which they can and cannot easily account.

12.1.1. Hooke's Model

Robert Hooke was a professor of geometry at Gresham College (England). He presented his model in lectures to the Royal Society of London in 1682, which were published 2 years after his death (Hooke, 1705/1969). Hooke proposed a geometric model of memory in which there is an account of time in the brain. According to Hooke's model (Hintzman, 2003b), each memory is formed at the soul's point of

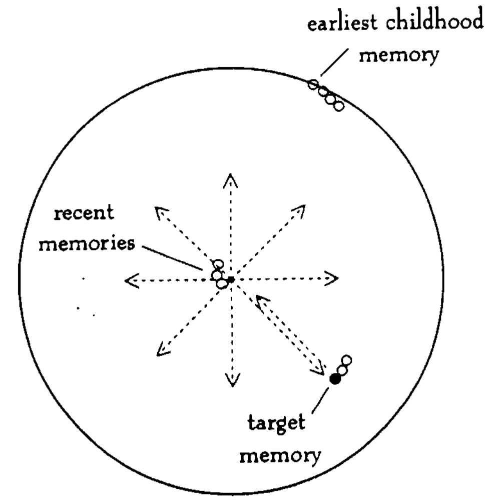

Figure 12.1: Hooke's model of memory. See text for explanation. (Reprinted with permission from Hintzman (2003b). Copyright 2003 by The Psychonomic Society).

interaction, and pressure from newly formed memories displace each memory outward, in an ever-growing sphere, shown in a cross-sectional view in Figure 12.1. Hooke (1705/1969) proposed that there is:

> a continued Chain of Ideas coyled up in the Repository of the Brain, the first end of which is farthest removed from the Center or Seat of the Soul where the Ideas are formed; and the other End is always at the Center, being the last Idea formed, which is always the Moment present when considered: And therefore according as there are a greater number of these Ideas between the present Sensation of Thought in the Center, and any other, the more is the Soul apprehensive of the Time interposed (p. 140).

Hooke said that therefore "the Notion of Time is the Apprehension of the Distance of Ideas from the Center or present Moment. And so Time comes to be apprehended as a Quantity" (p. 140). One problem is that Hooke's model predicts that the apparent recency of a past event is a power function of actual recency, with an exponent of exactly 1/3 (Hintzman, 2003b). Actually, a logarithmic function fits recency judgments better than a power function does (Hinrichs & Buschke, 1968; Hintzman, 2000). Hooke's model is an interesting contribution, even if only for historical reasons.

12.1.2. Bartlett's Contribution

Bartlett (1932/1997) reported a series of influential studies of human remembering. Although he did not focus on time *per se*, Bartlett's book, *Remembering: A Study in Experimental and Social Psychology*, had a large impact on memory research and theories. In his studies, people heard stories or saw drawings. Up to many years later, they were asked to reconstruct (tell or draw) them. Their reproductions were simpler and more regular than the original. Bartlett proposed that people had used schemas (structures containing related information about a concept) in order to encode and remember information. People also used inferences about what must have happened in the story or what must have been seen in the drawing. Bartlett proposed that remembering involves a *reconstruction* of what a person experienced.

Bartlett's view fits nicely with recent findings that contextual information is involved in event dating and duration timing. When people date an event or remember the duration of an episode that they experienced, they make inferences. In the case of event memory, people date an event based on inferences involving other facts (i.e., semantic memory information) that may help them remember the approximate date. In the case of remembered duration, people estimate a duration based on comparisons to other, similar durations, as well as facts about time. Bartlett also emphasized that the term *remembering* is more appropriate than the term *memory*, because the underlying processes involve dynamic acts of reconstruction, not static retrievals of fixed memory traces. His discovery is partly what led us to emphasize the terms *remembering* and *timing* instead of the terms *time* and *memory* in this chapter.[1]

12.1.3. Murdock's Conveyor-Belt Model

Murdock (1972, 1974) proposed a model in which each memory is put on a metaphorical conveyor belt and recedes into the distance over time. Thus, relative recency judgments become less accurate as events age. In this analogy, judging relative recency of events is like judging the relative distance of objects. It is relatively easy for a person to judge that an object 1 m distant is closer than an object 11 m distant, but it is more difficult for a person to judge that an object 101 m distant is closer than an object 111 m distant, even though the two objects are separated by 10 m in both cases. Like all unitary memory-strength models, this model cannot explain the many findings that contextual associations are important in recency judgments. However, it can perhaps explain some of the recent findings that remembering may involve the impressionistic retrieval of age-related information from memory traces (see later).

1. The differences between the words *time* and *timing* and the words *memory* and *remembering* are important. Although the words *time* and *memory* are nouns in their usual usage, the concepts denoted are not things, but actions. Thus, the words *timing* and *remembering* (verb forms) are appropriate. We mainly use them in this chapter (for reasons that will become clear), except when the historical context suggests the use of the words *time* and *memory* (nouns).

12.1.4. Contextual-Change Model

Fraisse (1957/1963) reviewed empirical findings on various kinds of temporal judgments, including duration judgments, and he proposed that "the length of a duration depends on the number of changes we perceive in it" (p. 218). Subsequently, Block (1990, 1992; Block & Reed, 1978) proposed a contextual-change model, in which a person makes a retrospective duration judgment by assessing the amount of change in cognitive context that occurred during the duration. The term *cognitive context* refers to the circumstances surrounding the occurrence of an event. Wickens (1987) said that context is the "environmental surround [that] is essentially irrelevant to the central task, whose demand characteristics remain the same regardless of the context" (pp. 138 – 139). Viewed in this way, contextual information may involve a person's emotions, the surrounding physical environment, and other such factors (Block, 1992). We discuss contextual information in more detail later in this chapter.

The contextual-change model assumes these memory-encoding processes: (a) During the duration, the person encodes events into memory; (b) Contextual associations are automatically encoded along with each event; and (c) Contextual elements change continually during the duration, although these changes may vary from relatively slow to relatively fast. The contextual-change model also assumes these memory-retrieval processes: (a) At the time a retrospective duration judgment is made, the person assesses the availability of events tagged with the relevant context; (b) Other contextual associations are also automatically retrieved; and (c) The person bases a retrospective duration judgment on the number of different contextual associations that are retrieved, perhaps in a sampling process relying on the availability of varied contextual associations.

12.1.5. Attentional-Gate Model

Most models of timing the present — prospective duration-judgment processes — are based on attentional processes, but still, those judgments rely on both working- and long-term memory functions. An example is the attentional-gate model (Block & Zakay, 1996; Zakay & Block, 1996, 1997). This model is an elaboration of the scalar-timing model (for a review, see Church, 1978; see also Chapters 3 and 9), which was designed to account for animals' timing behavior. The main difference between the attentional-gate model and previous scalar-timing models is that an attentional gate is interposed between the pacemaker and the accumulator. The attentional gate is needed to explain the impact on timing of the amount of attentional resources allocated for timing in a given situation. The attentional gate allows pulses generated by the pacemaker to accumulate only when the gate is opened, which requires attentional resources. Although Lejeune (1998) questioned the need to propose both a switch and a gate in the timekeeping process, separating these components is the best way to account for two different functions: attending to a duration-onset signal and attending to time during a duration (Zakay, 2000). In the scalar-timing model, the switch was required to serve these two very different functions.

According to the attentional-gate model, prospective timing involves the following component processes (see Figure 12.2):

1. A pacemaker emits pulses at a fairly constant rate, although that rate may be affected by arousal level.
2. The flow of pulses reaches an attentional gate. If more attentional resources are allocated for timing, the gate allows more pulses to pass through a switch to an accumulator.
3. The meaning assigned to a situation (a signal) influences a switch. The switch allows pulses to accumulate when a target interval starts, and it stops pulses from accumulating when the target interval ends (or if there is an interruption in it). Thus, the switch is responsible for monitoring a correspondence between the

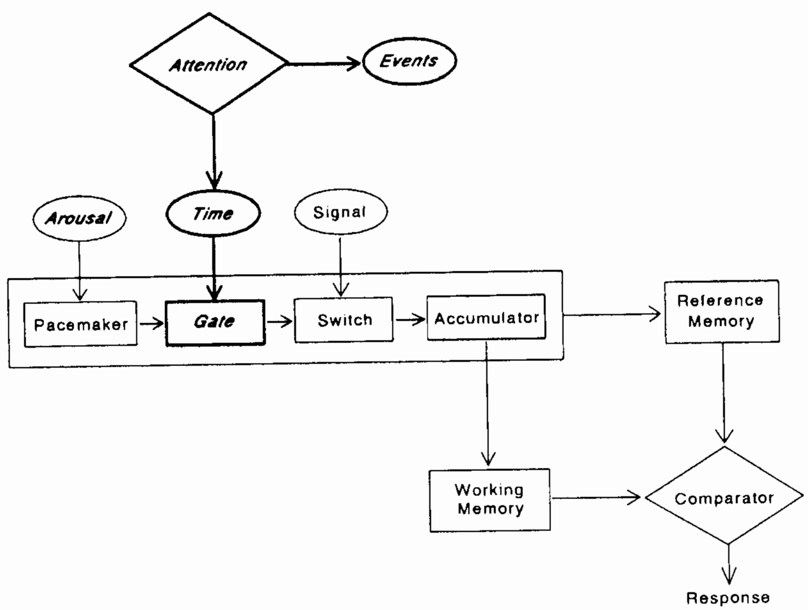

Figure 12.2: The attentional-gate model, adapted from Zakay and Block (1996) and Block (2003). See text for explanation. (Adapted with permission from Block (2003). Copyright 2003 by Hogrefe & Huber Publishers).

number of pulses that are allowed to pass through to the accumulator and the duration of a meaningful target interval.
4. The accumulator counts the number of pulses that were transmitted to it. This count depends on both the attentional gate and the switch. The count is a representation of the duration of an interval under specific conditions.
5. If a target interval must be reproduced, decision processes are employed. The number of ongoing pulses that are counted in the accumulator is constantly being compared with the previous number of pulse counts stored in reference memory and working memory. When a match is obtained, the reproduction is terminated (a response is made). If a target interval has to be produced, a representation of that interval is retrieved from long-term (reference) memory. The rest of the process is the same as in duration reproduction.

The analysis of the process outlined by attentional-gate model clearly indicates that the dependency on memory systems is high because working memory and reference memory are compared on a regular basis, and that comparison results in a decision concerning a response. (For additional discussion of the crucial role of decision processes in prospective timing, see Wearden, 2004). Working memory is therefore the bottleneck in the timing process in that it consumes many of the attentional resources demanded by prospective duration judgment (e.g., Brown, 1997; Fortin & Breton, 1995).

12.1.6. Temporal Context Model

Howard and Kahana (2002) recently proposed a formal model of the encoding of temporal information, which they called the *temporal context model*. As the name of the model implies, it focuses on contextual associations, and it has little to say about time-related processes *per se*. Figure 12.3 (upper panel) shows an earlier model, which Howard and Kahana called the *random context model*. In this model, the current temporal context (T) is associated with the current input event (F), but only random noise influences inputs (t^{IN}) to T. Figure 12.3 (lower panel) shows Howard and Kahana's temporal context model. It assumes that rather than being driven by random contextual fluctuations, retrieval of prior contextual states drives contextual change, or what they called *drift*. In this model, the item-to-context associative matrix (M^{TF} and M^{FT}) produces a tight coupling between the current input event and the temporal context. The temporal context model makes many of the same assumptions about contextual encoding and contextual change as earlier proposals concerning temporal dating of autobiographical events (Friedman, 1993, 2001), as well as concerning the role of contextual changes in duration timing (Block, 1990; Block & Reed, 1978). The temporal context model represents a preliminary step to integrating models of event dating and duration timing in a contextual framework. Additional formal modeling of this kind may be productive.

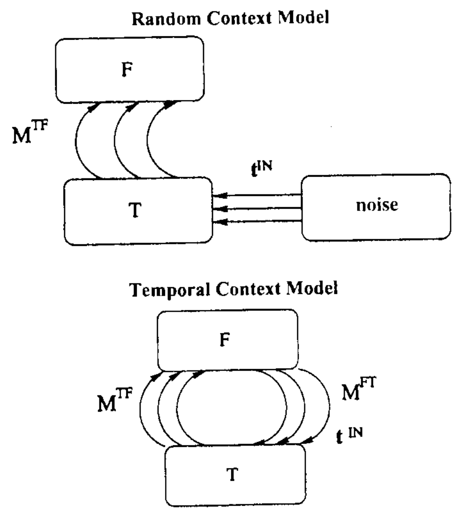

Figure 12.3: The random context model and the temporal context model, from Howard and Kahana (2002). See text for explanation. (Reprinted with permission from Howard and Kahana (2002). Copyright 2001 by Elsevier Science (USA)).

12.2. Timing the Past: Evidence

When people make temporal judgments about past events and episodes, sometimes the judgments concern their temporal location or recency (usually with an autobiographical reference), and sometimes the judgments concern their duration. These two kinds of judgments may involve some similar processes of remembering.

Research on event dating has a relatively long history. We first review some laboratory studies in which people experienced events and subsequently (usually within a few seconds or minutes) were asked to estimate the temporal position or recency of target (test) events. Then we review some nonlaboratory studies in which people experienced everyday events and subsequently (usually weeks, months, or years later) were asked to make temporal memory judgments on target (test) events. Evidence from laboratory and everyday-memory studies converges, suggesting that two major kinds of processes are involved: People may make event-dating judgments by relying on contextual information, by relying on a time-related property of the memory trace itself, or by relying on both.

12.2.1. Laboratory Studies of Past Event Dating

In an early experiment (Hintzman & Block, 1971, Experiment 1), people viewed a series of 50 words, one at a time, under incidental-memory conditions, at least as far

as temporal information was concerned: They were told to pay attention to the words for a subsequent memory test, the nature of which was not specified. Thus, they were not forewarned that the test would require event dating. After the series was presented, people were shown the words in random order and were asked to judge the approximate temporal position of each of them in the previous series. Although their performance was far from perfect, they were able to make these judgments with some accuracy. One major finding was particularly interesting: Temporal position judgments for events that had occurred near the start of the series of events were relatively more sensitive to changes in actual temporal position than were temporal position judgments for events that had occurred during the middle or near the end of the series. This is the opposite of what is predicted if temporal position judgments are based on the decaying strength or other similar attributes of memory traces, which would make older events less discriminable than more recent events (cf., Brown, Neath, & Chater, 2007). Additionally, people apparently encode and remember temporal position information even under incidental-memory conditions, and the encoding of this information seems therefore to occur in a relatively automatic way.

Subsequent experiments clarified and extended this finding. In one of them (Hintzman, Block, & Summers, 1973), people viewed two separate series of words. Afterwards, they were unexpectedly asked to judge whether each word had occurred in the first series or the second series, and then to judge whether it had occurred near the beginning, middle, or end of the series. Although their judgments were far from perfect, people were able to make these judgments with some accuracy: They were only about 43–62% correct in dating a word to the actual series of words; they were about 60% correct in dating a word to the actual third of the episode. The kinds of errors that they made were especially revealing. If a person incorrectly judged that a word had occurred in a particular series, he or she nevertheless tended to judge that it had occurred in the correct part of the series. Thus, incorrect event dating was not strictly along a unitary temporal dimension. This finding suggests that people based their position judgments at least partly on incidentally encoded contextual information instead of on a continuous scale of absolute time.

Two kinds of findings suggest that contextual information is automatically encoded (although it is not necessarily, and probably not, automatically retrieved). First, people can make reasonably accurate event-dating judgments even under incidental-memory conditions (e.g., Hintzman & Block, 1971). Second, accuracy of event-dating judgments is little or no better under intentional-memory conditions than under incidental-memory conditions (e.g., Auday, Sullivan, & Cross, 1988). Thus, people automatically encode contextual information when they experience events.[2] When people later need to make an event-dating judgment, they can use contextual information (along with logical inferences based on it) to remember the approximate time at which an event occurred.

2. This process, which underlies event dating, is apparently not limited to humans. Scrub jays are able to remember how long ago they cached food items (Clayton & Dickinson, 1998, 1999).

In one of the earliest systematic studies of recency discrimination (Yntema & Trask, 1963, Experiment 2), people saw a long series of words (under intentional-memory conditions). Occasionally, a pair of words appeared, and the person was asked to judge which of the words had appeared more recently. The number of other words that had intervened since each of the target words had appeared was systematically varied over a wide range. The ability to judge recency was a function of the relative recency of the two words. Recency discrimination improved to the extent that the more recent word had occurred recently and that the spacing between the two words had been large. Yntema and Trask (1963) raised the question: "May items in memory be assumed to carry time-tags?" (p. 73). Interestingly, their data are well fit by a logarithmic function (Hintzman, 2000), although Yntema and Trask did not make particular note of this finding.

Hintzman (2003a) conducted three experiments in which he showed people a very long series of words, one at a time, with some of them repeated. The use of a relatively long series creates a so-called *steady-state* condition, which is characterized by few, if any, changes in cognitive context. Each item served as a presented item and as a test item. Subjects were asked to make a recognition-memory (*new/old*) judgment, then a recency judgment if they recognized an item as being *old* (presented earlier in the series). In the first two experiments, Hintzman varied word attributes (orthographic frequency and word concreteness) so that some words would be more memorable than others. He found that recency judgments depended only slightly on the inherent strength, or memorability, of the words; recently judgments did, however, reflect actual recency. In a third experiment, subjects made only recognition memory judgments (specifically, confidence that they had earlier seen a word). The relative effect of actual recency on recognition confidence was much smaller than the effect of actual recency had been in the first two experiments, which suggests that recognition memory and recency judgments are based on different memory properties. Thus, a relatively time-based process was dissociated from recognition memory processes *per se*.

More recently, Hintzman (2004b) also showed people a very long series of items (nouns or first names), one at a time. The rate of presentation of each item was subtly varied such that there were periods of relatively fast presentation rate and periods of relatively slow presentation rate. People did not notice these changes in presentation rate, and there is no evidence that they used them to make recency judgments. He found that recency judgments were directly related to the amount of time that had elapsed since the target word had occurred, and that they were not a function of the number of intervening items. In a follow-up experiment, Hintzman (2005) presented items (first names and pictures), using a methodology similar to that used in his earlier experiments (i.e., Hintzman, 2003a). Once again, recency judgments were "especially sensitive to some unknown, time-specific cue" (p. 862).

Along with Yntema and Trask's (1963) findings, these findings suggest that under conditions in which people are not able to remember any useful contextual information, they can nevertheless remember the approximate recency of an event by relying on some aspect of the memory trace that may serve as a time-specific cue. Thus, recency judgments may be based on an age-related property or properties of a memory trace. Converging evidence comes from studies of everyday memory, which we now consider.

12.2.2. Everyday-Memory Studies of Past Event Dating

Important evidence on how people date past events comes from so-called *everyday-memory* or *autobiographical-memory* studies. In these studies, people typically are asked to record everyday events in writing, such as in a diary, and to include the exact date and time of the event. Many weeks, months, or years later, they are given their own description of some of these events and are asked to make a judgment about when each event occurred. People can make these judgments with some accuracy. However, their judgments reveal systematic biases, called *scale effects*: People may show relatively good accuracy in remembering that an event occurred during a particular time of day but show relatively poor accuracy in remembering the day, month, or year during which the event occurred (Friedman & Wilkins, 1985). Thus, people may remember fine-grained temporal information better than they remember coarse-grained temporal information. This finding rejects the view that memory for recency is based solely on information that relates to time *per se*, such as time tags that are monotonically related to the passing of time. Friedman (1993, 2001; see also Shum, 1998) suggested that people may also rely on a so-called *location-based process*, which involves judging the recency of an event by remembering relevant contextual associations. The caveat is that distinctive contextual associations must have been encoded, which they were apparently not in some of Hintzman's (2003a, 2004b, 2005) laboratory studies.

Most evidence on everyday, autobiographical memories seems to require an explanation in terms of remembering contextual associations. However, some recent evidence requires an explanation in terms of remembering temporal information *per se*, or a so-called *distance-based process*. For example, Friedman (1991) found that 4- to 8-year-old children can often accurately remember the relative recency of two events, one they had experienced 1 week earlier and another they had experienced 7 weeks earlier. This was the case even though the children could not remember the day, month, or season during which each event had occurred. Apparently the children were not relying on contextual associations to landmark events, such as a birthday party, a summer vacation, or a religious holiday (see Chapter 11). Friedman (2001) proposed that the children based their memory for the recency of a past event on a subjective impression of the age of the memory trace, not on a process of remembering the location of the event in a contextualized pattern of events. Importantly, Friedman and Kemp (1998) found that this impressionistic information is a monotonically decelerating function of the actual age of the event: Changes in event dating are more rapid at first (i.e., during the preceding few months); after that, changes in event dating are more gradual. Figure 12.4 shows their findings from an experiment in which young children judged the recency of their latest birthday. The children seemed to be relying on a "direct impression of the ages of events" (Friedman & Kemp, 1998, p. 155). As shown in Figure 12.4, the children's estimates can be fit by either a power function

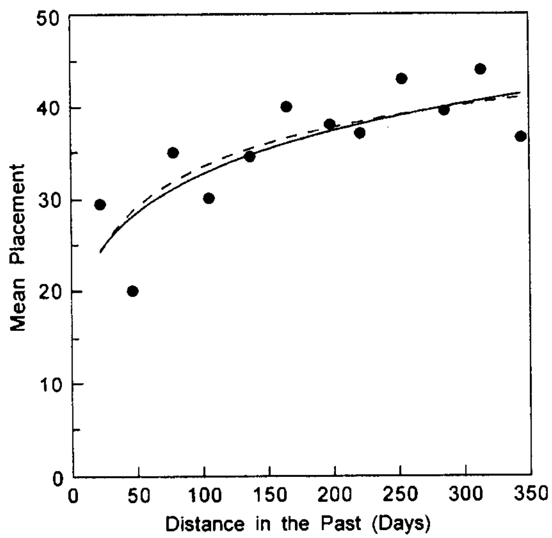

Figure 12.4: Event dating estimates by 3 – 6-year-old children, from Friedman and Kemp (1998, Study 3). Mean placement (estimate) of recency of latest birthday is shown as a function of its actual recency (in days). The best-fitting power function (solid line) and the best-fitting logarithmic function (dashed line) are shown. (Adapted with permission from Friedman and Kemp (1998). Copyright 1998 by Elsevier Publishing).

or a logarithmic function, which are extremely similar. The data are obviously too noisy to decide between the two functions.[3]

12.2.3. Past Event Dating: A Two-Process Model

Findings of both laboratory and everyday-memory studies support a two-process model of event dating. A person may remember the approximate date of a past event by retrieving either (a) contextual associations, along with inferences based on them, or (b) some age-related property or properties of the memory trace that does not involve contextual associations. The former implicates a *location-based* process and the latter implicates a *distance-based* process. Although a location-based process may

3. It is unclear which of the two functions best fits recency and other temporal judgments. The properties of a power function are better than those of a logarithmic function in modeling the forgetting of item information (Wixted & Carpenter, 2007), and it remains to be discovered why the same would not also hold for temporal memory judgments.

yield accurate information in many situations (and may therefore be more frequently used in autobiographical event dating), in other situations a person may have to rely on the more impressionistic information provided by a distance-based process.

12.2.4. Laboratory Studies of Past Duration Timing

The present chapter focuses on remembering, and retrospective duration timing is especially relevant. Because no unique sensory organ or perceptual system subserves timing (Gibson, 1975), most theorists emphasize relatively high-level processes involving memory. Studying how humans and other animals make duration judgments reveals and clarifies these processes (Block & Zakay, 1996; Zakay & Block, 1997).

One fairly general finding on retrospective timing, or remembered duration, is that if a person remembers a greater number of events from the time period, he or she tends to estimate the duration as being longer (Ornstein, 1969). Even if people estimate duration by remembering events, they undoubtedly do not try to retrieve all available memories of events from the time period. Instead, they probably rely on an availability heuristic, in which they remember a duration as being longer to the extent that they can easily, quickly, and vividly remember some events that occurred during the time period.

Remembered duration is not simply based on the availability of individual events; other factors are involved (Block, 1974; Block & Reed, 1978). Changes in cognitive context lengthen remembered duration more than do increases in the number of stimulus events encoded and retrieved. Remembered duration lengthens if people perform different kinds of information-processing tasks during a duration instead of a single task (Block, 1992; Block & Reed, 1978). This is attributed to changes in an aspect of cognitive context called *process context*. In addition, if there are more changes in environmental context, or in the encoding of environmental stimuli, during a time period, the remembered duration of it lengthens (Block, 1982, 1986). Other evidence also suggests that changes in emotions during a time period lengthen remembered duration (e.g., Block, 1982). In short, evidence reveals that the remembered duration of an episode is influenced by changes in cognitive context, including (but not limited to) process-context, environmental-context, and emotional-context changes.

12.2.5. Everyday-Memory Studies of Past Duration Timing

Very few researchers have studied retrospective timing, or remembered duration, under everyday-memory conditions.[4] Consider, however, a monumental study in which 1015 people were each unexpectedly asked to make one retrospective verbal

4. The main reason is that a person can usually provide only one judgment in the retrospective paradigm, because after a person is asked for a duration judgment, he or she is aware that duration timing is relevant and necessary, which is the definition of the prospective paradigm.

estimate (in seconds, or minutes and seconds) of the duration of an activity in which they had just engaged (Yarmey, 2000). A unique method was used, an "opportunity sampling procedure," in which people "were [unobtrusively] timed with a stopwatch while they participated in some specific event" (p. 48). The events, or activities, were either called *invariant* or *variant*, depending on the number of changes during a given activity. An example of an invariant activity is "one cycle of fitness training circuit" (780 s), and an example of a variant activity is "eating in a restaurant" (also 780 s). The duration of each activity ranged from 4 to 5008 s (83 min and 28 s), an unusually wide range of durations.[5]

We adapted these data (Yarmey, 2000, Table 1) and created Figure 12.5. Panel A shows that mean duration judgments were relatively accurate, which contrasts with Yarmey's (2000) description of the duration estimates as being "relatively imperfect" (p. 52). However, people showed the typical tendency to overestimate shorter durations and to slightly underestimate longer durations. These data are well fit by straight lines, which on log–log coordinates reflects the typical finding that duration estimates are a power function of actual duration, with an exponent slightly less than 1 (Eisler, 1976). A somewhat clearer picture emerges when the duration judgments are expressed in terms of a commonly used measure, the duration-judgment ratio — the ratio of estimated duration to actual duration (see Figure 12.5, Panel B). These data show more clearly that people overestimated the relatively short-duration events. Note that the duration-judgment ratio is relatively large for short-duration events compared to long-duration events. They also clearly show their other finding: The duration-judgment ratio is significantly larger for variant events than for invariant events. Although this finding may be interpreted in several ways, it seems to support the hypothesis that retrospective duration judgments lengthen as the degree of segmentation of the episode increases (Poynter, 1983, 1989) or as the number of contextual changes during the episode increases (Block, 1978). This interaction between event duration and type of activity (invariant versus variant) is consistent with other evidence suggesting that changes in cognitive context are less rapid as a duration lengthens (e.g., Hintzman & Block, 1971). Thus, these findings support the hypothesis that changes in cognitive context (in the case of variant events in contrast to the case of invariant events) lengthen remembered duration.

12.2.6. Evidence on Duration Neglect

A general rule of perception is that the overall strength of a percept is a function of the physical intensity of the stimulus that evokes the percept multiplied by its exposure duration (so-called *Bloch's Law*). Bloch's Law holds for ongoing

5. The difference between a variant event and an invariant event may not be the same for short- and long-duration events, because short- and long-duration events may differ on other dimensions. However, Yarmey used an unusually wide range of examples of relatively short-duration and relatively long-duration events, which may reduce the importance of any such confounding.

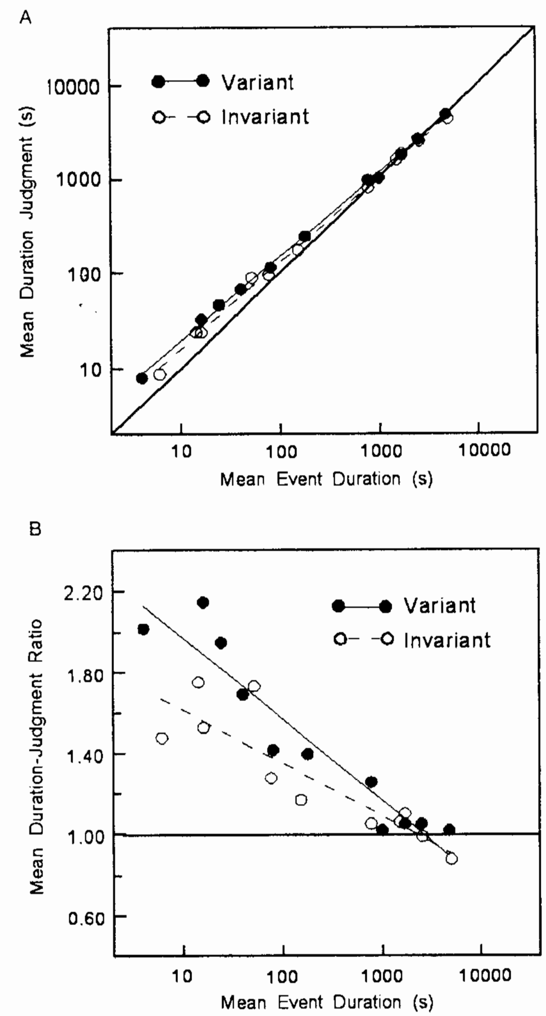

Figure 12.5: Retrospective duration judgment of everyday activities, adapted from Yarmey's (2000) data reported in his Table 1. Panel A shows mean duration judgment (in seconds) on a logarithmic scale as a function of mean event duration (in seconds) on a logarithmic scale for invariant events and variant events; the best linear fit, reflecting a power function, is shown for each type of event. Panel B shows mean duration-judgment ratio (the ratio of estimated event duration to actual event duration) as a function of mean event duration (in seconds) on a logarithmic scale for invariant events and variant events; the best linear fit is shown for each type of event. (Adapted with permission from Yarmey (2000). Copyright 2000 by Wiley InterScience).

stimulation and for brief durations (mainly those under 100 ms). Still, it is of interest to study the role of duration when people are making retrospective evaluations of temporally extended streams of hedonic experiences like pain or pleasure. Fredrickson and Kahneman (1993) found that in such cases people exhibit what they called *duration neglect*, which is a systematic bias towards ignoring the duration of a past experience. Research in various domains revealed that people were utilizing a heuristic called the *peak-and-end rule*, according to which retrospective global evaluations of hedonic sequences were mainly based on the peak level of the experience (i.e., the maximum level of pain or pleasure) and on the respective level at the end of the sequence. It appears that Gestalt characteristics of a sequence, such as its trend and rate of change in addition to the momentary experiences at the most intense and final moments, dominate the overall retrospective evaluation (for a summary, see Ariely & Zakay, 2001).

The consequences of the peak-and-end heuristic imply violations of temporal monotonicity. For example, longer episodes with same average level of pain or pleasure might be evaluated as less aversive or more attractive, respectively, than shorter episodes with same average levels of pain or pleasure (Langer, Sarin, & Weber, 2005). In addition, increasing sequences are evaluated as more attractive than decreasing ones (Loewenstein & Prelec, 1993). If a short interval with a moderate level of pleasure is added to an episode characterized by a high level of pleasure at its end, the overall retrospective hedonic value of the sequence can be lower than that of the original episode. An opposite result is obtained with discomfort (Redelmeier & Kahneman, 1996). These findings hold for various stimulus types such as pain (e.g., Ariely & Carmon, 2000) and positive affect (Fredrickson & Kahneman, 1993).

The tendency of people to underweight the duration of an experience when they retrospectively evaluate its overall hedonic value was empirically confirmed in several studies (e.g., Redelmeier & Kahneman, 1996). Rode, Rozin, and Durlach (2007) found duration neglect when people were asked to rate the hedonic value of meals composed of several dishes, but there was no evidence for peak, primacy, or recency effects in terms of attractiveness of meals.

The duration-neglect phenomenon contradicts not only Bloch's Law but also the discounted utility model. The discounted utility model predicts that people should consider the duration of an experience while evaluating its utility. This model also predicts that people should not consider features of an experience such as improvement or deterioration over time and certainly not for peak and end levels (Ariely & Loewenstein, 2000).

Hsee, Abelson, and Salovey (1991) introduced the term *evaluability effect*. Their argument is that when evaluating items separately or one at a time, attributes that are not easily judged independently are given little weight. However, when the same items are evaluated in an environment that facilitates comparison to other items, respondents place much greater weight on the same attributes. Note that in almost all the studies in which duration neglect was found, sequences were evaluated separately or one at a time. Another important issue that should be noted is that hedonic evaluations were always done retrospectively and therefore duration estimation was never asked for explicitly. Therefore, even if duration was estimated, it was estimated retrospectively. Following on the logic of the evaluability effect, Ariely and Loewenstein (2000) argued that when encoding experiences, particular attention is given to salient attributes, which in most cases do not include duration because this is not an important attribute to which one is attending. However, when making decisions about future events, the picture changes. Decision makers take into account both expected intensity and expected duration. The reason is that when choosing between two sequences, duration is an important attribute that should be compared, and therefore attention is allocated for its evaluation. These predictions were empirically supported.

Temporal relevance refers to the degree to which taking duration into account is essential for interpreting the meaning of a situation or for making optimal decisions in terms of adaptation to a relevant environment (Zakay, 1992). On the basis of the above-mentioned arguments and findings, we suggest that whenever temporal relevance is high, duration neglect will not be found. In other words, whenever duration is relevant, attention is paid to it and therefore it will be taken into account. This hypothesis directly leads to a prediction that if duration is estimated prospectively, duration neglect should be eliminated. This prediction was empirically supported by Rinot (2000), who asked participants to evaluate the degree of discomfort created by sequences of tones while also prospectively judging the duration of the sequences. Rinot found that the overall hedonic value of each sequence was mostly influenced by its duration, and the impact of the peak and end levels of loudness have much lower impact than that of duration. As expected, the higher the loudness and the degree of discomfort of a sequence, the longer was its estimated duration, probably because participants wanted the unpleasant situation to end as soon as possible and therefore they paid more attention to time than when the level of discomfort created by the tones was reasonable.

Zakay (2002) asked participants to evaluate the overall degree of suffering expected in regard to different scenarios of dental treatments. Dental treatments were described by the following four binary parameters: treatment's duration, peak pain level, pain level at the beginning of the treatment, and pain level at the end of the treatment. All 16 combinations of these parameters were evaluated. A conjoint analysis revealed that treatment duration was the strongest predictor of the hedonic value attached to each sequence, followed by the peak and end levels of pain. Somewhat similar findings were reported by Gilbert, Pinel, Wilson, Blumberg, and Wheatley (1998), who found that people tend to overestimate the duration of their affective reactions to negative events, like the dissolution of a romantic relationship or a rejection by a prospective employer. They called this the *immune neglect effect*, analogous to the way that people minimize the strength of their physiological immune system. We suggest that this finding, which indicates paying a high level of attention to duration, is caused by the explicit demand to judge duration as well as by the high relevance of duration in the type of episodes studied in this research.

As for the cases in which episodes are evaluated separately and retrospectively, it might be that duration is actually being retrospectively estimated but this is not taken into account because the temporal relevance of duration for evaluating the hedonic value of a single past event is not high.

Interestingly, the peak-and-end heuristic represents an important characteristic of retrospective duration judgment. Cognitive models of retrospective duration judgment are based on the assumption that the more contextual changes occur during an episode (Block, 1990), such as changes when the episode is segmented by high priority events (Poynter, 1983, 1989), the longer is its remembered duration. Undoubtedly, the starting and ending events of an episode are involved with two important contextual changes that also segment the episode and are easy to remember. Thus, regardless of the actual duration of an episode, the starting and ending events have a high impact on both the retrospective hedonic level attached to the episode as well as on its retrospective duration estimation. This hypothesis should be empirically tested. Some support for it might be found in a study conducted by Ariely and Zauberman (2000), who addressed the question of the impact of temporal spacing of an episode on its overall hedonic value. They found that breaking an episode into smaller pieces by the inclusion of short pauses moderated the duration neglect bias. They hypothesized that the breaks cause the individuals to perform interim evaluations of the episode segments, such that in retrospective judgments these evaluations rather than the instant utility levels are aggregated. We argue that by segmenting the episode its remembered duration also increased, and its impact on the overall hedonic value of the episode became emphasized. If this is the case, then perhaps duration is not really neglected. Instead, its impact on the retrospective hedonic value of a single past episode is not revealed because of the low level of duration relevance in such evaluations.

The duration neglect phenomenon illustrates broader characteristics of both prospective and retrospective duration judgments. For prospective judgments, duration neglect is a result of the high dependency of prospective duration judgments on the allocation of attentional resources for timing (see later). Whenever attentional resources are not allocated for timing, duration is neglected because fewer pulses enter the accumulator. (For an explanation, see our earlier description of the attentional-gate model). Temporal illusions — such as when a duration filled with a demanding cognitive task is prospectively judged as shorter than an equivalent time interval filled with a less demanding cognitive task — may be a result of duration neglect in the first case attributable to the attentional resources required by the demanding task.

For retrospective judgments, duration is neglected whenever there are few contextual changes, and this is reflected by temporal illusions, such as when an interval filled with contextual changes is perceived as retrospectively longer than an otherwise equivalent "empty" interval.

Although the role of remembering in retrospective duration judgment is critical, it is of interest to note that memory systems also play an important role in ongoing (prospective) duration judgments, but in this case the main role of memory is exhibited not so much in processes of retrieving information from long-term memory as in ongoing processes that mainly involve short-term (working) memory.

12.3. Timing the Present: Evidence

In experiments on how people time present durations, they are asked to judge the experienced duration of an episode while it is in progress, and the paradigm is called the *prospective paradigm* (see Chapters 2 and 4). In this kind of temporal judgment, people are aware that timing is relevant (Zakay, 1992). In many dual-task experiments, a person must time a duration while also performing either a difficult, an easy, or no secondary task. If a person must perform a simultaneous nontemporal task during a time period, experienced duration varies with the difficulty of the attentional demands that are required by it. Thus, if the processing task is more difficult, experienced duration decreases, as revealed by longer productions or smaller verbal estimates of duration (Hicks, Miller, & Kinsbourne, 1976; Zakay, 1993; Zakay & Block, 1997). In everyday life, prospective timing usually occurs in a dual-task condition in which attention is shared between nontemporal and temporal information processing. Nontemporal information processing involves external stimuli (along with accompanying internal cognitions), but excludes temporal attributes of those stimuli. Temporal information processing involves time-related aspects of external stimuli, as well as time-related internal cognitions (such as what is called *attending to time*).

Many findings reveal that temporal information processing requires access to some of the same working-memory resources that are needed for attending to nontemporal information (Brown, 1997). If a person is able to allocate relatively more attentional resources to processing temporal information, experienced duration increases. For example, if a subject must track the duration of several concurrent events, timing accuracy decreases as a function of the number of events that must be timed (Brown, 1997). If a subject is told how much attention to allocate for temporal information processing and how much to allocate for stimulus information processing, experienced duration depends on the relative allocation of resources (Brown, 1997; Macar, Grondin, & Casini, 1994; Zakay, 1992, 1998; see also Chapter 4).

For these reasons, most theorists emphasize the role of attentional resource allocation, along with working-memory processes, in experienced duration (e.g., Block & Zakay, 1996; Brown, 1997; Zakay & Block, 1996). The attentional-gate model described earlier (see Figure 12.2) emphasizes these component processes. Consider, however, whether there may be an alternative way to account for prospective timing without needing to assume an underlying pacemaker-accumulator system. Block (2003) proposed that interval timing may involve a comparison of apparent ages of events. Assume that the apparent age of an event (which is the inverse of its apparent recency) increases as a negatively accelerated function of physical time, just as Friedman and Kemp (1998; see Figure 12.4) and others have found. When a person is producing a duration, he or she terminates the production when the apparent age of the start (duration-onset) signal matches the average apparent age for that approximate duration, an average that has been learned in the past. When a person is verbally estimating a duration, he or she compares the apparent ages of the start-of-duration and end-of-duration (or the present) events in memory, and then translates this information into numerical time units based on verbal translations learned in the past and retrieved from long-term memory. These comparisons may involve impressionistic information about the apparent ages of the events, a distance-based process (Friedman & Kemp, 1998; see also Chapter 11).

Block (2003) further noted that if prospective timing involves comparing the relative ages of the start and end events in memory, the process by which attentional demands during the duration influence the comparison must be clarified. If there are few attentional demands during the time period, the usually assumed process involves attending to time (such as by opening the attentional gate wider or more often) and, as a result, encoding more temporal information. Block's alternative suggestion is that attending to time involves effortful retrieval of automatically encoded information concerning the apparent age of the previous act of attending to time. Because the apparent age of a past event increases as a negatively accelerated function of physical time, if age information is retrieved more frequently, the accumulated age information increases in an unusually large way. Thus, the process involves accumulating samples of relatively large differences in relative age. In contrast, if a person attends to time less often, apparent age of a past event (such as a start-of-duration event) is only retrieved a few times, and the power-function aging process is nearer to an asymptotic level. This model, which Block called a *memory-age model* of prospective duration timing, is a plausible alternative to pacemaker models of interval timing.

A process that underlies the memory encoding and retrieval of age information was originally called *study-phase retrieval* (Hintzman, Summers, & Block, 1975) and more recently has been called *recursive reminding* (Hintzman, 2004a). Recursive reminding is the relatively automatic way in which information associated with an earlier event is retrieved by the same event or a similar event. The retrieved information includes contextual associations, which contain information on apparent recency or age of the previous occurrence. Thus, when a person attends to time, that action will automatically retrieve information about the previous action of attending to time, including the apparent age of that earlier action. More frequently attending to time, such as when timing is relevant and attentional demands are relatively low, therefore increases experienced duration (shortens productions and lengthens verbal estimates) by means of this recursive retrieval process, and perhaps also by increasing the segmentation of the duration.

12.4. Timing the Future: Evidence

Duration-judgment processes are also sometimes needed in relation to future acts. For example, if a person decides at 19:30 to listen to the news at 20:00, he or she should monitor the elapsing time in order not to miss the news. This type of cognitive activity is traditionally called *prospective memory*, and it is usually defined as remembering actions that need to be performed in the future (Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995), or as memory of future intentions (Rude, Hertel, Jarrold, Covich, & Hedlund, 1999). Another definition of prospective memory is that it involves "the ability to formulate intentions, to make plans and promises, and to retain and execute them at the appropriate place and time" (Graf, 2005, p. 305). Thus, it requires a process of retrieving from long-term memory a person's intentions for future actions (Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997).

There are two types of prospective remembering: event based and time based. In event-based prospective remembering, the intention is to perform an action when a specific event occurs (e.g., tell my colleague something important when I encounter him or her): In this case, what is needed is to successfully recognize the event (perception of my colleague), and then to successfully retrieve from memory the intention (the important information). The event, in this case, serves as a retrieval cue.

In the case of time-based prospective memory (e.g., remembering to take a medicine 30 min from now), the main goal is to remember to perform an intended act at a specific future time. Time-based prospective remembering is a central cognitive ability that is needed for ensuring optimal daily activity (Brandimonte, Einstein, & McDaniel, 1996). A process of duration judgment should start such that when an interval (such as 30 min) has elapsed, the intention is retrieved, and then the intended action is performed. Thus, timing has a central role: A cue, based on a prospective duration judgment, must retrieve the intention in order for the person to perform the action.

Harris and Wilkins (1982) were the first researchers to suggest that time-based prospective remembering is related to duration judgment. They proposed a test-wait-test-exit model according to which an effective time monitoring is a key to a successful performance of the prospective memory task. According to this model, a person monitors time in a series of feedback loops, until he or she decides that the appropriate time for performing the task has arrived. Einstein et al. (1995) reported empirical support for this model. They found a high correlation between the number of times a person looked at an external chronometer during a time-based prospective remembering task and the amount of success in actually performing the intended prospective task. This test-wait-test-exit model, however, does not specify the cognitive processes that underlie this correlation. Observing an external chronometer is simply a behavioral indication of some internal cognitive processes. Indeed, Ceci and Bronfenbrenner (1985) found that with 10–14-year-old children, number of clock checks did not predict success in a time-based task. They claimed that task success is predicted not by the number of clock checks but by their effective and strategic allocation toward the end of the task. In addition to that, they found that children failed more in a home context than in a laboratory context. A plausible explanation for this finding is that the laboratory context enabled fewer attentional distractions than the home context since the laboratory context itself is a cue of the task and thus children's resilience to potential distractions is higher than at home. This explanation is supported by Craik's (1986) argument that prospective remembering depends on self-initiated attention-demanding processes. Einstein and McDaniel (1990) proposed a similar explanation.

Graf and Uttl (2001) argued that successful prospective memory requires both prospective and retrospective components, or stages. In the prospective stage, the cue for retrieving an intention from memory must be noticed and recognized, and in the retrospective stage the intention must be successfully retrieved. Thus, the basic difference between event-based and time-based prospective remembering is in the prospective stage. Graf and Grondin (2006) claimed that the domains of time perception and of prospective memory are connected and involve at least some of the same high-level cognitive processes or mechanisms. They suggested that time-based prospective memory is composed of several distinguishable components or functions. They argued that clock-checking strategies and time-related processes are likely to be critically involved in only some of them. Block and Zakay (2006) argued that the test-wait-test-exit model is not adequate in that it does not explicitly address several questions, such as exactly what is being tested. They also suggested that prospective remembering does not involve any special cognitive or memory systems. Instead, they said that "prospective remembering relies on the functioning of well-known attention and memory systems" (p. 25). Regarding time-based prospective remembering, at least when it involves short-term periods in the range of seconds and minutes, they said that a process of prospective duration judgment is automatically evoked by the intent to perform an act after a certain interval. This claim is related to the notion of temporal relevance (see p. 383). Undoubtedly, temporal relevance is high in time-based prospective remembering situations.

Thus, it is possible to describe the process that underlies time-based prospective remembering as the encoding of an intention to perform action after a specified interval has elapsed. This intention automatically initiates a prospective duration-judgment process that continues until the person perceives that the interval has elapsed. When this happens, the intention may (or may not) be retrieved from memory, and the intended action is (or is not) performed.

Observing an external clock is nothing more than an external behavior that indicates the allocation of attention for prospective duration judgment. However, there are individual differences in the translation of the allocation of attention to the external behavior, and consequently the correlation between the number of clock checks and the quality of the performance of the intended action is not a good indicator of the internal process. In addition, failure to perform the task may result from either a failure in the prospective duration-judgment process or in the retrieval of the specific intention. In both cases, the major potential source of failure is attentional distraction. For example, if one decides to take his or her medicine after 30 min and during that interval the person is engaged by a television program, he or she might be surprised after the 60-min program has ended that more than 30 min has elapsed. This is an example of the impact of attentional distraction (the television program) on prospective duration judgment, which is well explained by the attentional-gate model or the memory-age model. However, it might be that even if the person accurately judged the 30-min interval, he or she will not remember what the intention was, and this failure might also be a result of the distraction by the television program.

Evidence reveals that some of the same processes are involved in event dating and duration timing, including those that are implicated in time-based prospective remembering. One process used in event dating depends on retrieving contextual associations that were automatically encoded along with the event. Similarly, the main process used in retrospective duration timing is one that depends on changes in contextual associations that were automatically encoded during an episode. In prospective duration timing, attention to time and the retrieval of information about previous, similar durations from memory is required. In prospective remembering, especially those that are time based, similar kinds of attentional and memory processes are required, along with retrieval from memory of the intended action.

12.5. Summary and Conclusions

We reviewed theories and research on several ways in which timing and remembering are intimately interrelated. We focused mainly on the encoding and retrieval of temporal information. Various theories, or models, dating back to Hooke's (1705/1969), make various proposals about processes by which people: (a) date past events — that is, remember the autobiographical temporal location (or recency) of events; (b) estimate the duration of past episodes (encoded either without or with prior awareness that timing is relevant); and (c) time intentions for future actions. Some of the theoretical models make similar claims, although the differences among them have been difficult to test, and some major issues are still unresolved.

In this chapter, we reviewed evidence on timing the past (including recency and retrospective duration judgments), timing the present (prospective duration judgments), and timing the future (time-based prospective memory actions). We have highlighted that some similar processes are implicated in each of these situations, although there are also some important differences. However, a grand unified model that accounts for similarities and differences among these timing and remembering situations remains somewhat elusive. Any unified model should consider the following general findings:

1. People use two kinds of information in event dating (i.e., remembering when a past event occurred): contextual associations (a location-based process), and age-related properties of memory traces that do not involve contextual associations (a distance-based process). Some recent evidence reveals that memory traces inherently contain time-related information, although contextual information is also used to make temporal judgments about past events.
2. A process of remembering contextual associations, and a comparison of differences between them, is also involved in retrospective duration timing: Remembered contextual changes are used to estimate past durations. In addition, event dating and duration timing may both involve acts of reconstruction based partly on logical inferences.

3. Contextual information may also be involved in prospective duration timing, at least according to the memory-age model (Block, 2003).
4. Viewing duration neglect as a general characteristic of duration-judgment processes suggests that unlike objective time, subjective time is not continuous, and is used only when it is relevant and when it falls within the range of an attentional spotlight. While reading an interesting book during a vacation, duration is neglected because it is not relevant. In other words, subjective time does not "flow" unless it is relevant and therefore receives attention.
5. Time-based prospective remembering apparently involves many of the same processes that are required for prospective timing (Block & Zakay, 2006).

Any unified model of temporal remembering must also take into account the inherent variability of the underlying processes and the resulting variability of time judgments. Just as chronobiological timing displays "sloppiness," or lability (Campbell, 1990), so does psychological timing. People can remember approximately when past events occurred, but lability attributable to scale effects and other contextually based errors in dating events is common (Friedman & Wilkins, 1985). People can estimate durations both retrospectively and prospectively, but those judgments are notoriously variable, as revealed by measures such as the coefficient of variation (Block & Zakay, 1997). The peak-and-end heuristic in hedonic judgments also reveals violations of temporal monotonicity (Ariely & Zakay, 2001). People often perform time- or event-based actions at approximately the correct future time, but failures to do so are all too common (Block & Zakay, 2006).

Although Aristotle worded it differently (McKeon, 1941), timing requires remembering, and remembering involves timing. This is illustrated in Salvador Dali's famous painting, "The Persistence of Memory." Both timing and remembering rely on complex interactions of processes and consequently are fluid, sloppy, and labile. Nevertheless, research reveals important overall effects, which we have highlighted in this chapter and which must also be highlighted in future, more unified models.

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