Time and Mind II: Information Processing Perspectives

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Chapter 3:

Psychological timing without a timer: The roles of attention and memory[*]

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Abstract

Scalar-timing models have dominated explanations of animal timing. Scalar-timing theorists explain interval timing by assuming an internal-clock mechanism. For several reasons, this kind of model, along with other timing-with-a-timer models, may not provide a necessary and sufficient account of timing behavior and time experiences. Investigations of various human temporal judgments reveal influences of factors that may not be parsimoniously subsumed in an internal-clock framework. Evidence suggests that people make recency and serial position judgments by relying on both the apparent age of a past event (distance-based-processes) and on contextual associations to past events (location-based processes). When ongoing duration timing becomes important and salient, as in the human prospective duration judgment paradigm and the analogous animal paradigms (e.g., the peak procedure), attentional allocation becomes an important additional variable. I describe a memory-age model of processes involved in attending to time, which applies to relatively short-duration prospective timing. In retrospective timing, people apparently judge relatively long durations by relying mainly on availability of events and contextual changes associated with them. Timing-without-a timer models of psychological time (i.e., pacemaker-free models, such as the present memory-age model) need to be tested so that they can be evaluated against timing-with-a timer-models. I briefly review some neuropsychological evidence on temporal perspective, which involves remembering the past, experiencing the present, and anticipating the future. Researchers should consider whether timing-with-a-timer models adequately explain the many influences of attention and memory on duration experiences, as well as on the human ability to maintain a normal temporal perspective.

Introduction

Some of the first psychologists discussed and investigated the ways in which animals, including humans, experience and estimate time. Animals encode temporal aspects of stimuli and durations, remember those temporal aspects, and use stored temporal information to perform adaptive actions. In addition, humans (and perhaps

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other, more advanced animals) orient themselves in time, remembering past events, experiencing present events, and planning or imagining future events. For more than a century, researchers have investigated the mechanisms or processes by which the mind solves problems concerning time. This research has produced abundant and diverse findings, as well as equally abundant and diverse theories.

Models of psychological time include those that assume one or more timer (internal clock, or pacemaker), and those that do not. Research focusing on the former kind of model, which is called *timing with a timer*, often differs considerably from research focusing on the latter kind of theory, which is called *timing without a timer* (Block, 1990; Ivry & Hazeltine, 1992). The two kinds of theorists often focus on different species, speak different languages, and use different paradigms. Many, although certainly not all, researchers studying timing with a timer focus on nonhuman animals (e.g., rats and pigeons), describe findings in operant conditioning terminology, and use a few relatively simple paradigms. Many, although certainly not all, researchers studying timing without a timer focus on humans, describe findings in cognitive terminology, and use diverse and relatively complex paradigms.

My early theorizing was in the cognitive tradition, emphasizing timing without a timer. I criticized internal clock models and discussed ways in which they are limited (Block, 1990). However, in the first *Time and Mind* volume (Helfrich, 1996), I proposed (along with Dan Zakay) a timing-with-a-timer model, the so-called *attentional-gate model* (Block & Zakay, 1996; see also Zakay & Block, 1996, 1997). This model represents a recent exception to the general characterization of timing-with-a-timer models as being focused on simple operant conditioning paradigms involving nonhuman animals.

I will argue here that timing-with-a-timer models do not provide a necessary and sufficient account of all aspects of psychological time. I will first briefly describe the most successful and widespread kind of model of timing with a timer, scalar-timing models. I will discuss some of their limitations. Finally, I will make the case for a class of models of timing without a timer by connecting psychological time with cognitive findings on attention and memory.

Timing with a timer: Scalar-timing models

Scalar-expectancy theory is an associative model of learning that is closely related to scalar-timing models, a class of psychophysical models of psychological time. Here, I will discuss them as if they were the same. Scalar-timing researchers have proposed several modules, including a pacemaker, a switch, an accumulator, a working memory, a reference memory, and a comparator (see Figure 1). Two previous authors (Church, this volume, chapter 1; Wearden, this volume, chapter 2) outlined some details of these models and the many findings they can explain, so I will summarize them here. The typical finding is that the psychophysical function relating physical duration and psychological duration is approximately linear. This is explained in terms of a pacemaker producing pulses at a fairly constant rate (with Poisson variability) and the accumulation of the pulses in working memory as a linear function of physical time. The typical finding that Weber's Law holds over a fairly wide range of durations is explained in terms of the process used in making the time estimate, which involves comparing the pulse total in working memory and the stored total in reference memory.

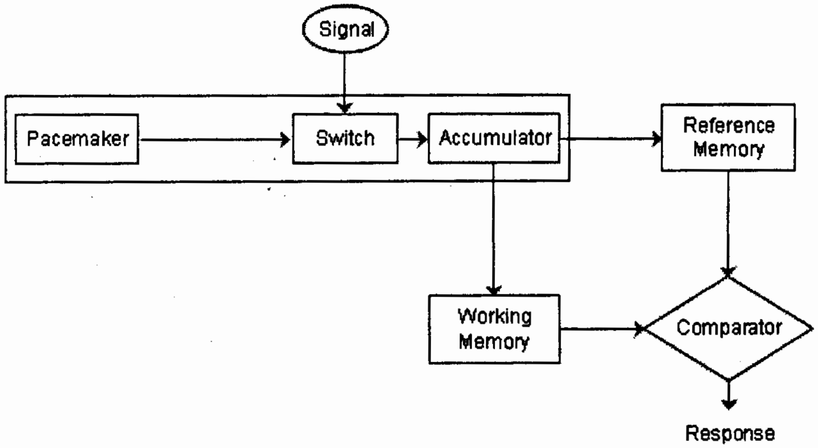

Figure 1: A typical scalar-timing model. Adapted from Gibbon, Church and Meck (1984, p. 54)[1]

Scalar-timing models have several drawbacks, or limitations:

1. No constant-rate pacemaker has been identified in the brain. This is perhaps not a serious problem, because researchers may ultimately find a neural basis for the pacemaker. Although some researchers have claimed to do so, this evidence is relatively weak (for a recent review, however, see Gibbon, Malapani, Dale, & Gallistel, 1997). Researchers have already revealed a neural basis for the pacemaker that underlies circadian rhythms, and they have shown that neurons in the suprachiasmatic nucleus can function endogenously, even when disconnected from normal inputs from nonvisual retinal photoreceptors (Freedman et al., 1999). Evidence that a pacemaker subserves interval timing on the order of seconds and minutes has, however, remained elusive.

2. Researchers advocating scalar-timing models have mainly used only a few paradigms, such as the peak procedure and the bisection task (see Wearden, this volume, chapter 2). In addition, until relatively recently, scalar-timing researchers have mainly studied rats and pigeons. Although some scalar-timing researchers have recently investigated counting, foraging, and other animal behavior, as well human timing behavior (e.g., Wearden, this volume, chapter 2; Wearden & Culpin, 1998), most of the evidence comes from a few relatively simple paradigms.

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3. Perhaps because it is relatively difficult to devise situations in which nonhuman animals must make various kinds of temporal judgments, the evidence supporting scalar-timing models has come mainly from studies in which animals estimate the duration of a single stimulus or an interval between two stimuli (see, however, Church, this volume, chapter 1). Most scalar timing experiments have used so-called *empty* durations, or gaps between stimuli, during which no external stimuli are presented, and the animal has no external information to process. Scalar-timing models cannot easily explain a wide variety of human research using so-called *filled* durations. The human literature on psychological time, which I will discuss next, also includes various other kinds of judgments, such as temporal location and recency judgments. Scalar-timing models were not designed to explain these kinds of judgments, and they cannot easily be adapted to do so.

4. Scalar-timing models are not easily able to explain effects of attention on psychological time, which are widespread and well documented in the human cognitive literature (see later). Most discussions of the role of attention in scalar timing are relatively brief, usually attributing attentional effects to processes operating on the proposed switch, such as simple delays in closing it (see, however, Lejeune, 1998).

5. Many of the findings that scalar-timing models explain are generic. For example, the basic notion—the so-called *scalar property* of timing—is found in psychophysical judgments involving a wide variety of physical dimensions for which a ratio scale is appropriate (Eisler, 1965). The finding that the standard deviation of estimates increases proportionally with the mean estimate is typical for many dimensions, and the approximate constancy of the coefficient of variation (standard deviation divided by mean estimate), along with the closely related Weber's Law, is not unique to the time dimension. Only the pacemaker and accumulator components are unique to the time dimension. With only slight modification (e.g., substituting external stimulus information for the pacemaker), scalar-timing models could easily become scalar-perceiving models.

6. The typical scalar-timing assumption that time estimates are a linear function of physical duration is not widely supported. Eisler (1976), for example, reported that psychological time is a power function of physical time, with an exponent less than 1.0 (about 0.9). More recently, Staddon and Higa (1999) suggested that psychological time is a logarithmic function of physical time, which they explained in terms of a process of habituation.

Timing without a timer: Attention and memory models

In the rest of this chapter, I will lay some of the groundwork for theories that do a better job of integrating findings concerning psychological time with well-established findings concerning attention and memory. I will first distinguish studies that focused on when a past stimulus (event) occurred, how long a single stimulus lasted, and how long an interval lasted.

Temporal location judgments

Two separate processes apparently subserve memory for the times (temporal locations) of past events, which are usually called *distance-based processes* and *location-based processes* (for a recent review, see Friedman, 2001). Distance-based processes depend on the continually changing amount of time that has elapsed between some past event and the present, whereas location-based processes depend on the relationships between some past event and relatively unchanging memories for past time patterns. Neither distance-based processes nor location-based processes requires any sort of pacemaker-accumulator system or any *special* encoding of time. Distance-based processes involve a judgment of the vividness of the memory for the event. Location-based processes involve inferences about other events in which it was embedded. Consider some of the evidence.

Distance-based processes. Surprisingly little evidence requires an explanation in terms of distance-based processes. Nevertheless, there is some. Friedman (1991), for example, found that 4- to 8-year-old children could accurately remember the relative recency of events, one that they had experienced one week earlier and another that they had experienced seven weeks earlier. However, the children could not remember the day, month, or season during which each event had occurred. Friedman (2001) argued that the children based their memory for the time of a past event on an impression of its age, not on a process of remembering the location of the event in a pattern of events. Friedman and Kemp (1998) found that this impressionistic information is a decelerating function of the actual age of the event, with most of the change occurring during the preceding few months (see Figure 2). The best-fitting power function had an exponent of only 0.20.

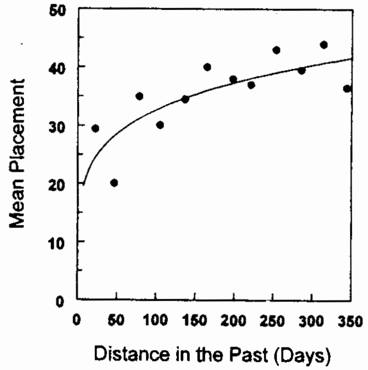

Figure 2: Mean placement of birthday as a function of actual distance in the past. Adapted from Friedman and Kemp (1998, p. 357)[2]

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Location-based processes. Location-based processes are probably more important and more accurate than distance-based processes for human adults. These depend mainly on the relatively automatic encoding of events in a rich cognitive context, along with inferences at the time of retrieval and judgment. In one experiment (Hintzman & Block, 1971) participants viewed a series of 50 words without being forewarned that temporal judgments would be required. They were subsequently asked to judge the temporal position of each word in the series. If they remembered the word, they were able to judge its temporal position with some accuracy (see Figure 3), especially those near a landmark event, the start of the word series. In subsequent experiments, participants viewed words during two separate durations, again under incidental conditions (Hintzman, Block, & Summers, 1973). Afterwards, they were asked to judge whether each word had occurred during the first or the second duration, and then whether it had occurred near the beginning, middle, or end of it. They were able to make these judgments with some accuracy. However, if a participant incorrectly judged that a word had occurred during a particular duration, he or she nevertheless tended to judge that it had occurred in the correct part of it. Thus, remembered events did not randomly migrate to temporally adjacent locations. These location-based temporal position judgments apparently rely on incidentally (i.e., relatively automatically) encoded contextual information. As such, contextual information enables people to locate events on a relative scale of psychological time, not on a continuous scale of absolute time (cf. Hintzman, 2001, 2002).

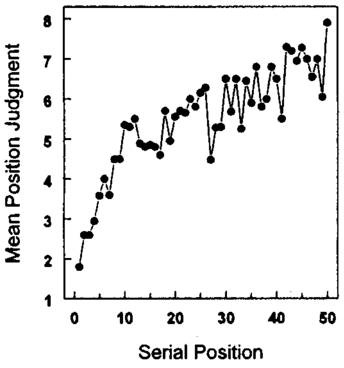

Figure 3: Mean judgment of temporal position judgment (on a scale from *1* to *10*) as a function of the serial position of a word in a series of words. Adapted from Hintzman and Block (1971, p. 299)[3]

Similar evidence comes from studies of autobiographical memory in which participants are asked to date personal memories of events that occurred relatively long ago, such as months or years in the past. Participants can temporally locate their personal memories with some accuracy. However, their judgments also reveal systematic errors called *scale effects*. For example, an event may be accurately remembered as having occurred during a particular time of day, but inaccurately remembered as to the day, month, or year (Friedman & Wilkins, 1985). Thus, recency judgments involve location-based processes, not just distance-based processes, and important contextual landmarks influence these processes (Friedman, 1996; Shum, 1998).

In short, evidence shows clearly that normal memory and cognitive processes are necessary and sufficient to explain memory for the time of a past event. The information is encoded relatively automatically, and there is no need to assume an internal-clock mechanism, such as the pacemaker-accumulator system of scalar timing models. Indeed, if one were to assume such a mechanism, one would need to postulate that a separate internal clock is switched on for each experienced event. The brain undoubtedly does not contain a separate pacemaker and accumulator for each event that is experienced. This has important implications for studies of interval timing in animals and humans, which I now discuss.

Stimulus timing

Theories of timing must distinguish between two kinds of duration judgments: judging the duration of a single stimulus (or the relative duration of two stimuli), and judging the interval between two events. These two kinds of time judgments almost certainly involve different processes.

Animals can learn to make one response to a relatively short-duration stimulus and another response to a relatively long-duration stimulus (Fetterman, 1995). If they are tested on novel stimuli presented at intermediate durations, they usually bisect (that is, show mathematical indifference) at the geometric mean of the two learned stimuli. If a novel test stimulus is presented at an intermediate duration and a delay is interposed between it and the time the animal is permitted to respond, the animal tends to remember that the test stimulus is shorter than if no delay had been interposed. This reliable finding, called the *choose-short effect*, seems to indicate that the animal has forgotten some of the temporal information. Although a scalar-timing model could assume that some pulses are lost from the accumulator over time, evidence suggests that the choose-short effect is better explained in terms of proactive interference (stimulus generalization) or other well-known memory phenomena (Kraemer, Mazmanian, & Roberts, 1985). People can also remember the approximate duration of each event in a long series of events, and they can do so even if they were not expecting to perform the task (Hintzman, 1970). Duration information is apparently encoded relatively automatically as an integral part of the experience of an event.

Interval timing

Scalar-timing models cannot easily explain all the findings concerning judgments of the duration of a stimulus. Consider now whether scalar-timing models can explain all the findings concerning judgments of intervals between events. Many researchers have investigated the processes involved in judging the duration of a

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relatively long empty interval (i.e., one containing no changes in external stimuli) or judging the duration of a relatively long filled interval (i.e., one containing changes in external stimuli, such as a series of stimulus events). In these cases, duration is not a property of a single stimulus event.

Scalar-timing models were originally proposed to explain interval timing—and *only* interval timing. They have successfully explained and guided much research on interval timing. In one common paradigm, called the *peak procedure*, rats or pigeons learn to expect reinforcement after a fixed interval (usually on the order of tens of seconds), and during this interval no external stimuli are presented. Because it is not uncommon for an animal to begin responding after only about one-third of the required interval has elapsed, one could argue that one or more proposed modules (pacemaker, switch, accumulator, memory, and comparator) must operate in a rather imprecise way. The animals' difficulties are perhaps reflected in the common finding that stereotyped behavior chains (so-called *adjunctive behaviors*) occur during the interval (Killeen & Fetterman, 1988). These adjunctive behaviors may reflect an adaptive strategy to provide timing in the absence of an accurate internal clock.

Scalar-timing proponents have investigated interval timing under limited conditions, at least until relatively recently. Typically, an animal is observed behaving during an empty interval, one during which no changing external stimuli are presented or processed. Although some scalar-timing researchers have recently been investigating more ecologically valid conditions, with changing external stimulation during the interval (e.g., Lejeune, Macar, & Zakay, 1999), most of what is known about interval timing comes from human research.

Human researchers investigating interval (duration) timing work mainly in a cognitive tradition, and they study effects of varying information-processing tasks that a person must perform during a time period. Duration timing reveals interactions among conditions prevailing when a time period is experienced and those prevailing when it is judged (Block, 1989). For example, different findings are sometimes obtained depending on the choice of duration-estimation task. The usual tasks involve production, verbal estimation, reproduction, and similar methods (for a review, see Zakay, 1990).

Prospective timing. The method most analogous to the peak procedure in animal timing is production, in which a person is asked to delimit an objective interval to estimate a verbally stated duration, such as "30 seconds." People make such estimates under what is called the *prospective paradigm*, in which they are aware that timing is relevant and important. I refer to prospective duration judgments as reflecting *experienced duration*. If an experimenter requires a participant to perform other information-processing tasks during the production, experienced duration varies along with these attention-demanding processes. If there are fewer stimuli or if a processing task is easy, experienced duration increases, as revealed by shorter productions or larger verbal estimates of duration (Hicks, Miller, & Kinsbourne, 1976; Zakay, 1993; Zakay & Block, 1997). Prospective timing is therefore a dual-task condition in which attention is shared between nontemporal and temporal information processing. Nontemporal information processing is directed toward external stimuli (along with accompanying internal cognitions), excluding attributes involving time. Temporal information processing is directed toward 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 attentional resources that attending to nontemporal information does. Experienced duration increases if a person allocates relatively more attentional resources to processing temporal information. If a person is told how much attention to allocate for stimulus information processing and how much to allocate for temporal information processing, prospective duration judgments depend on the relative allocation (Brown, 1997; Macar, Grondin, & Casini, 1994; Zakay, 1992, 1998). If a person must track the duration of several concurrent events, timing accuracy decreases as a function of the number of monitored events (Brown, 1997).

For this reason, most theorists emphasize the role of attentional resource allocation (Block & Zakay, 1996; Brown, 1998; Macar et al., 1994; Thomas & Weaver, 1975; Zakay & Block, 1996). Some scalar-timing theorists have said that attention is needed to operate a switch between the pacemaker and the accumulator (Meck, 1984). Until recently, the attentional effect on the switch was limited to the requirement that the animal perceives the signal indicating that the interval had begun. Other than that attentional requirement, the typical scalar-timing model did not incorporate attentional effects in any serious way (see, however, Lejeune, 1998). This lead Zakay and me (Block & Zakay, 1996; Zakay & Block, 1996, 1997) to propose what we called an *attentional-gate model* of prospective duration judgments (see Figure 4). The main difference between this model and scalar-timing models is that an attentional gate is interposed between the pacemaker and the accumulator, and this attentional gate allows pulses produced by a pacemaker to be accumulated only when it is operated by attention. Lejeune (1998) questioned the need to propose both a switch and a gate, but there is a major theoretical difference between attending to the duration-onset signal and attending to time during the duration (see Zakay, 2000).

Scalar-timing models and the attentional-gate model are both pacemaker-accumulator systems. If one does not adopt the assumption that a pacemaker-accumulator system underlies prospective timing, what is the alternative? One possibility is that interval timing involves a comparing apparent ages of events. Assume that the apparent age of an event (which is the inverse of apparent recency) increases as a negatively accelerated (e.g., power) function of physical time, as in the findings of Friedman and Kemp (1998; see the present Figure 2).

When a person is asked actively to produce a verbally stated duration, the person terminates the production when the apparent age of the start (duration-onset) signal matches the average apparent age for that approximate duration that has been learned in the past. Analogously, in the peak procedure the animal responds to the extent that the apparent age of the start signal matches the apparent age of the start signal at the time of reinforcement during previous trials. When a person is asked to verbally estimate a past duration, the relevant comparison involves the apparent ages of the start-of-duration and end-of-duration events in memory, and the person translates this information into numerical time units based on similar comparisons stored in the past. When a person is asked to reproduce a past duration, the person encodes the apparent age of the start signal at the time the end signal occurs and then terminates the reproduction (as in the method of production) when the apparent age of the start of the reproduction is comparable to it.

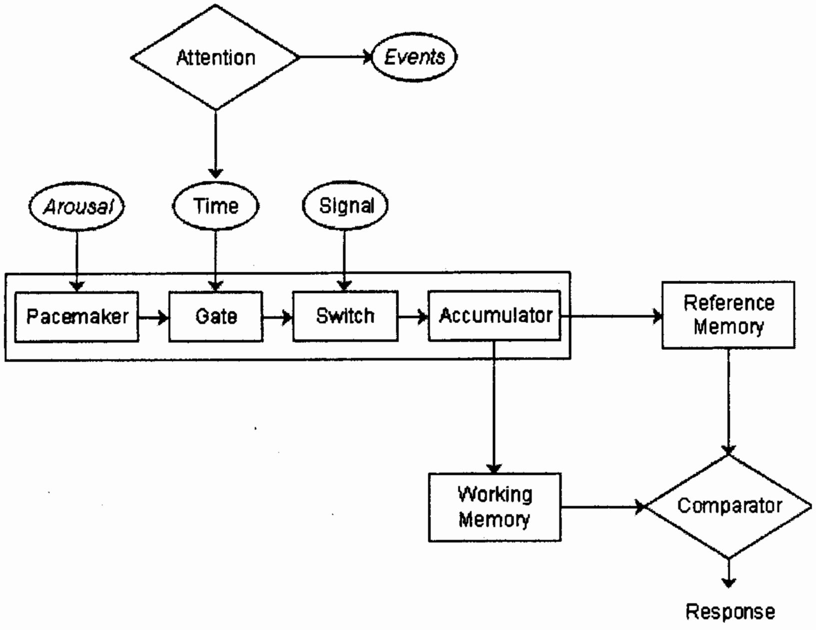

Figure 4: Attentional-gate model of prospective duration judgment. Adapted from Block and Zakay (1996, p. 182).[4]

If prospective duration timing involves comparing the relative ages of the start and end signals, the process by which information-processing demands during the duration influences the comparison needs to be clarified. If a person has few attentional demands during the time period, the typical explanation is that the person is able to attend to time more often and, as a result, stores more temporal information. What a person does when he or she attends to time has never been fully described. One possibility is that every act of attending to time involves retrieval of information concerning the apparent age of the previous act of attending to time. Because apparent age increases as a negatively accelerated (e.g., power) function of physical time, on every occasion that age information is retrieved, the accumulated age information increases in an unusually large way. In other words, the process involves accumulating samples of relatively large changes in relative age. If a person attends to time less often, or not at all, apparent-age information is only retrieved a few times, or not at all, and the power-function aging process is nearer to an asymptotic level. This model, which I call a *memory-age model* of prospective duration timing, is a plausible alternative to timing-with-a-timer models of interval timing.

A process that underlies the retrieval of age information was originally called *study-phase retrieval*. It refers to the relatively automatic way in which information associated with an earlier event is retrieved by the same event or a similar event (Hintzman, Summers, & Block, 1975; Tzeng & Cotton, 1980). The retrieved information is contextual in nature, including information on apparent recency or age of the previous occurrence. Attending to time may automatically retrieve information about the previous act of attending to time, including the apparent age of that act. Repeated acts of attending to time may increase experienced duration by means of this retrieval process, and perhaps also by increasing the segmentation of the duration (see later).

Retrospective timing. In contrast to prospective duration judgments, in the retrospective paradigm people do not know or suspect that they will be asked to judge duration until after the time period has ended. The animal literature has not provided any experimental evidence on retrospective duration judgments; such experiments are difficult or perhaps impossible to undertake. Without any previous operant or respondent conditioning, which would lead the animal to learn that timing is relevant, the experimenter must communicate to the animal that it should estimate a *past* duration. The animal must understand the communication and have some minimal concept of time as involving both past and present. According to Tulving (2002), only humans display what he called *autonoetic consciousness*. This kind of consciousness enables a human to grasp concepts of past, present, and future, and this kind of temporal perspective may be required for retrospective duration estimation. A clever future experimenter may devise a way to ask an animal, perhaps a nonhuman primate, to judge a past duration, and comparative psychological evidence may become available in the future.

Many researchers have studied prospective duration judgments, but few have studied retrospective duration judgments (for a notable exception, see Eisler & Eisler, 2001). The main reason is that after a participant provides a retrospective judgment, he or she will suspect that additional duration judgments will be requested. Thus, the paradigm becomes prospective. Collecting data on retrospective duration judgments requires many participants, because ordinarily each participant can provide only one estimate. The exceptions involve retrospective duration estimates of autobiographical events, or perhaps of several durations presented in the laboratory, but there are serious difficulties in interpreting such evidence. Later, I will discuss time-order effects.

Several kinds of variables influence the magnitude of retrospective duration judgments, or what I call *remembered duration*. Remembered duration increases if a person processed and can now remember a greater number of stimuli or more complex stimuli (Ornstein, 1969). However, remembered duration is not based simply on memory of individual events or their encoded complexity (Block, 1974; Block & Reed, 1978). In addition, information-processing demands do not influence remembered duration much, if at all (Block & Zakay, 1997; Hicks et al., 1976). Instead, changes in context increase remembered duration. These contextual changes may

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involve environment stimuli, internal stimuli, information processing strategies, and other such factors (Block, 1989). For example, remembered duration increases to the extent that a person performed different kinds of tasks during the time period. It increases if a person has had no previous experience in a particular environment (Block, 1982). It also increases if the time period was segmented by high-priority events, such as politicians' names inserted among names of animals (Poynter, 1989). Such segmentation may cause contextual changes when the high-priority events appear.

Retrospective duration judgments usually show what is called a *positive time-order effect*: The first of two equal time periods is remembered as being longer than the second (Block, 1982, 1985). This effect is somewhat counterintuitive: Some models predicts the opposite, a negative time-order effect attributable to older memories dropping out of storage, or fading with time (Ornstein, 1969). However, a person may encode a greater number of contextual changes during a novel experience, such as during the first of two durations experienced in the laboratory. Several findings suggest that contextual changes underlie the positive time-order effect. If the environmental context prevailing during the second duration is different from that prevailing during the first, the effect is eliminated (Block, 1982). If changes in emotions or mood that would ordinarily occur during the first duration occur instead during a preceding time period, the effect is also eliminated (Block, 1986). If the interval between two durations increases, so that the first one becomes relatively less recent and the second one becomes relatively more recent, the effect may reverse, becoming a negative time-order effect (Wearden & Ferrara, 1993). In this case, people may have difficulty remembering the contextual changes that occurred during the first duration.

Scalar timing models were not developed to explain retrospective duration estimates, and they have difficulty doing so. One problem is that durations of event sequences often overlap. Consider a situation in which a person drives a car for 90 minutes. During a 50-minute duration near the start of the car trip, the person listens to some music on the car stereo. Partially overlapping with this duration, the person opens and drinks a bottle of water during a 35-minute duration. After the car journey, the person may be able to provide reasonable estimates of the total duration of the journey, the duration of the music, and the duration of the water drinking (although these estimates may show considerable variability, especially relative to prospective estimates). Several concurrently operating internal clocks would be needed to explain this ability. In real-world situations such as this, the number of concurrently operating internal clocks could easily proliferate to a large number. In addition, many timing-with-a-timer models cannot explain why many information-processing variables (such as number and complexity of events, segmentation of events, and contextual changes) influence retrospective timing.

Perhaps the same kind of cognitive model that can explain prospective timing can also explain retrospective timing. For example, a person may retrieve and compare the apparent ages of the event that signaled the start of the duration and the event that signaled the end of the duration. This seems unlikely. In order for this simple model to be viable, it would have to explain the process by which the nature of events and contextual changes that occurred during the duration influence the apparent age of the start-of-duration signal, the apparent age of the end-of-duration signal, or the comparison of the two.

Prospective versus retrospective timing. Evidence from experiments that compared prospective and retrospective duration estimates suggests that different processes are involved in the two paradigms. Prospective judgments are usually larger in magnitude and smaller in variability than are retrospective judgments, and several variables influence duration judgments differently in the two paradigms (Block & Zakay, 1997). For example, prospective verbal estimates decrease if a person had performed a relatively difficult information-processing task, but retrospective estimates are not affected (Block, 1992; Hicks et al., 1976). In addition, retrospective estimates increase if a person had performed different information-processing tasks, but prospective estimates are not usually affected (Block, 1992; but see Brown, 1997). These findings suggest that different processes subserve duration judgments in the two paradigms.

In the retrospective paradigm, people probably do not attend to time much unless there is little information to process or a boring situation. Consequently, most models emphasize that retrospective estimates must rely on some aspect of episodic memory for events that occurred during the duration. Theorists have proposed that remembered duration is based on the "multitudinousness of the memories which the time affords" (James, 1890); stored and retrieved information, or "storage size" (Ornstein, 1969); remembered changes (Fraisse, 1963); encoded and retrieved contextual changes (Block, 1974); interval segmentation (Poynter, 1983); and other such constructs. In the retrospective paradigm, people may selectively attempt to retrieve memories of some events that occurred during the time period. Remembered duration increases to the extent that the events are more easily retrievable. Thus, people may use an availability heuristic. However, remembered duration is not based entirely on availability to memory of external events. Instead, people apparently judge a duration based mainly on the contextual changes that were automatically encoded in memory along with the external events (Block, 1982; Block & Reed, 1978). If a person is able to retrieve memories for more external events at the time of the retrospective duration judgment, more contextual information is also retrieved, because contextual information is activated when a person remembers an event. In the prospective paradigm, these contextual changes are also automatically encoded, of course, but they apparently play a minor role. Instead, the person may rely mainly on the changes in the apparent age of the events associated with each act of attending to time.

To state it differently, both distance-based information and location-based information may be used to make prospective and retrospective duration judgments. However, the relative importance of the two kinds of information may differ. In prospective timing, distance-based information may be relatively more important. Distance-based information (i.e., apparent age of a past event) is sensitive over the short time periods that are usually involved in prospective timing (seconds to minutes). Distance-based information may be the main information available to animals and children. In retrospective timing, on the other hand, location-based information may be relatively more important. Location-based information (i.e., contextual associations to events) is sensitive over the long time periods that are usually involved in retrospective timing (minutes, hours, days, weeks, or years). Location-based information may be the main kind of information that adult humans use to estimate relatively long time periods, especially those that occurred relatively long ago.

Temporal perspective

Most researchers investigating psychological time have focused on a person's ability to estimate when a past event occurred (recency or temporal position judgments), how long a past stimulus lasted (stimulus-duration judgments), or how long a passing or past series of events lasted (prospective or retrospective duration judgments). Another aspect of psychological time involves what is usually called *temporal perspective* (Block, 1979). Involuntary and voluntary shifts of attention to past, present, and future events change the contents of consciousness. At any moment, a person may be remembering a dinner conversation last night, focusing on what someone is saying now, or thinking about what to order for dinner tonight. Even though focal attention is different in these three cases, a person usually maintains awareness of the present context. As I have already noted, contextual elements seem to be automatically associated with events, whether the event is mainly externally triggered (as in perceiving) or mainly internally generated (as in remembering or planning). A person may be able to remember that he or she (a) last thought about the previous night's dinner conversation about 40 seconds ago, (b) read the word *contextual* about 15 seconds ago, and (c) thought about tonight's dinner plans about 50 minutes ago. Although focal attention and corresponding awareness may be oriented toward the past (remembering), toward the present (perceiving), or toward the future (planning), the present context is always just outside of focal attention, and it becomes associated with the remembering, perceiving, or planning activity. This relatively automatic construction of context may give rise to the apparent continuity of our consciousness in spite of shifts from remembering the past to perceiving the present to planning the future.

Sometimes this does not occur. The literature contains descriptions of experiences of timelessness, which may accompany creative states, meditative states, or psychoactive drug-induced states of consciousness, among others (Block, 1979). Some people have reported wakening in a strange hotel room and not knowing, for a few seconds, where or when they are—that is, in what city they are, at what time of day it is, or even what day it is. This is reminiscent of the description of H.M., a patient who received a bilateral hippocampectomy. As a result of his inability to form new long-term episodic memories, H.M. lives in a present that extends only about 15 seconds back into the past. He said that his continual mental condition is "like waking from a dream" (Milner, 1970, p. 37). Although in people with an intact hippocampus this experience is usually brief, a typical description is that one loses the ordinary impression of time and place. Perhaps, for some unknown reason (probably involving the functioning of the frontal lobes, which may construct context and send contextual information to the hippocampus), the ordinarily automatic maintenance of the present cognitive context ceases to occur. H.M., whose frontal lobes were intact, could engage in planning, although he may not have been able to remember his plan if more than about 15 seconds elapsed between the planning and the opportunity to engage in the planned activity.

Tulving, along with his colleagues (Wheeler, Stuss, & Tulving, 1997), has recently discussed what he calls *chronesthesia*, "a form of consciousness that allows individuals to think about the subjective time in which they live and that makes it possible for them to 'mentally travel' in such time" (Tulving, 2002, p. 311). He argued that only humans older than about three or four years of age have sufficiently well developed frontal lobes to subserve chronesthesia. He also reviewed evidence on K.C., a neurological patient with multiple cortical and white matter lesions in both anterior and posterior parts of the brain, along with hippocampal damage. Like H.M., K.C. has no functional episodic memory: He cannot remember anything that happened to him personally more than about 15 seconds ago. Also like H.M., his working memory is intact, and he is an intelligent person. However, K.C. has little or no concept of his personal future. When he is asked to think about the next half hour or the next year, he says that his mind is "blank." Tulving (2002) concluded: "K.C. seems to be as incapable of imagining his future as he is of remembering his past" (p. 317). However, K.C. *knows* about time: He knows about clocks and calendars, and he can talk about what he and other people know about physical time, including what day it is, and so on.

In contrast to H.M. and K.C., who know about impersonal time, some patients with lesions of the dorsomedial nucleus of the thalamus show an impairment of temporal orientation that has been called *chronotaraxis* (Spiegel, Wycis, Orchinik, & Freed, 1955). In chronotaraxis, the patient is unable to know the season, the date, the day of week, or the time of day.

Models of psychological time, if they are to be complete and integrative models, will eventually have to include what researchers are beginning to discover about temporal perspective. Future, more integrative models will need to include awareness of present time and future time with awareness of the ages of past events, awareness of past event durations, and awareness of the durations of passing or past sequence of events.

Conclusion

Pacemaker-accumulator models of timing, such as scalar-timing models, are limited in scope. These models sufficiently account for some findings, especially on animal timing of stimuli and intervals, but they may not be necessary. Timing-with-a-timer models were originally devised to explain only interval timing, and they cannot easily explain other aspects of psychological time, such as remembering the approximate age of events, making retrospective duration judgments, and maintaining a temporal perspective.

Pacemaker-free models, on the other hand, provide a necessary and sufficient account of memory for stimulus duration and interval timing, as well as the other aspects of psychological time that I have discussed. They do so in a potentially integrative way, mainly by focusing on the role of attention and memory processes. Pacemaker-free models have not yet been developed to provide precise, mathematical predictions. However, in the near future they may be able to do so. Further exploration of pacemaker-free cognitive models of psychological time is needed.

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