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Models of Psychological Time

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Psychological time consists of three major aspects: succession, duration, and temporal perspective. *Succession* refers to the sequential occurrence of events (i.e., changes), from which an organism may perceive successiveness and temporal order. *Duration* refers to several different characteristics of events. Every event persists for a certain duration, which an individual may encode and remember. Events are separated by time periods, or intervals, that may contain other events, and the length of intervals plays a role in various aspects of psychological time. A relatively unified series of events forms an episode that continues for a certain duration, which an individual may encode and remember. *Temporal perspective*, the third aspect of psychological time discussed here, refers to an individual's experiences and conceptions concerning past, present, and future time.

This chapter reviews models and evidence concerning each of these three aspects of psychological time. It also focuses on problems with, or weaknesses of, the various models. No existing model can handle the variety of experimental evidence on psychological time.

MODELS OF PSYCHOLOGICAL TIME AS SUCCESSION

In the literature on psychological time, researchers have been somewhat less concerned with time as succession than with time as duration

(Michon, chapter 2, this volume). Nevertheless, considerable research has investigated judgments of simultaneity, successiveness, and temporal order of rapidly occurring, very brief-duration events. This work has been grounded primarily in models of biopsychological and sensory-perceptual processes. Researchers studying memory have done considerable recent work on issues and models concerning how people encode and remember the temporal order of events occurring over longer periods of time.

Simultaneity and Successiveness

Some classic studies on psychological time investigated the temporal resolution of perceptual systems. Various phenomena occur if brief stimuli are presented in such a way that the stimulus-onset asynchrony (i.e., the interval between the onset times of two stimuli) is less than several milliseconds. The perceptual systems differ somewhat in this regard, especially audition and vision, the two that researchers have studied most. An added complication is that certain kinds of phenomena occur when stimuli strike the same sensory-receptor areas (e.g., the same position on the cochlea of an ear or on the retina of an eye), whereas somewhat different phenomena occur when stimuli strike different receptor areas.

The monaural or binaural presentation of two brief auditory stimuli separated by less than a few milliseconds produces an experience of simultaneity–subjects fail to discriminate the two stimuli from a single stimulus. However, the auditory system is still extremely sensitive to relatively small temporal differences. Under optimal conditions, Exner reported successiveness if the stimulus-onset asynchrony of two binaurally presented stimuli was as short as about 2 ms (see Hirsh & Sherrick, 1961). If two auditory stimuli are presented dichotically (i.e., one stimulus to each ear) with a stimulus-onset asynchrony less than about .5 ms, people experience them as a single stimulus. Under these conditions, the perceptual phenomenon is spatial, rather than temporal: A sound source located away from the median plane normally produces such slight differences in asynchrony, and these differences are a cue that enable a person to localize the sound source. If the stimulus-onset asynchrony of two dichotically presented stimuli is greater than several milliseconds, however, people experience successiveness, with one stimulus located to the left and one to the right of the median plane.

Exner also reported that if two binocularly presented stimuli occur with a stimulus-onset asynchrony less than about 44 ms, they seem to be a single, unchanging stimulus. If stimuli repeatedly strike the same retinal areas with slightly longer interstimulus intervals, people experience flicker–temporal discontinuity of the stimuli. Other phenomena occur under conditions in which stimuli strike different retinal areas. Westheimer and McKee (1977) found that if two 100-ms visual stimuli strike spatially adjacent positions on a retinal surface, people report apparent movement of a single stimulus, even if the stimulus-onset asynchrony is very short (e.g., 3-10 ms). (Perhaps concomitantly, under these conditions they can also judge temporal order fairly reliably. As I mention later, however, people cannot always judge temporal order reliably under conditions in which they can discriminate successiveness reliably.) As the stimulus-onset asynchrony of two stimuli increases (e.g., 120 ms for two 100-ms stimuli, or an interstimulus interval of 20 ms), apparent movement becomes optimum, but it nevertheless depends on stimulus parameters (Kahneman & Wolman, 1970). At still longer intervals, people experience successive stimuli, but no apparent movement.

Psychological Moment

A number of studies have investigated several slightly different central (i.e., cortical) intermittency models of what Stroud (1955) originally called the *moment*, or "the least timewise element of psychological experience" (p. 180). These models, which have mostly fallen from whatever favor they originally had, are usually collectively called *psychological-moment*, or *perceptual-moment*, models. They originated with observations that people experience apparent simultaneity if a very short interval separates two or more brief visual stimuli. Although these models propose a central pacemaker immune to specific sensory-perceptual influence, virtually all of the studies investigating psychological-moment models have used visual stimuli (see Patterson, chapter 4, this volume).

Stroud's (1955, 1967) original proposal, which is usually called a *discrete-moment* model, claims that all incoming information is processed in nonoverlapping (i.e, temporally discrete) samples or scans and that the temporal order of stimuli within a scan is not preserved. Allport (1968) proposed a major alternative, a so-called *travelling-moment* model, which asserts that information is processed as if it is perceived through a continuously moving, fixed-duration window, rather than as if it is perceived in discrete, nonoverlapping samples. Regardless of model (discrete moment or travelling moment), early speculation linked the moment with a hypothetical scanning reflected in the alpha rhythm, which is 8-12 cycles/s, or about 100 ms/cycle. Different investigators have obtained varying evidence on the duration of this hypothetical time span of integration. For example, researchers have estimated the moment at about 90 ms (Hylan, 1903), 50-200 ms (Stroud, 1955), 140-170 ms (White, 1963), and 70-100 ms (Allport, 1968).

Although psychological-moment models such as Stroud's propose a central, neural pacemaker that is uninfluenced by external events, stimulus parameters such as duration and intensity heavily influence estimates of the moment. Efron (1970) found that the minimum duration of a visual or auditory perception is about 130 ms, and he suggested that this finding is interpretable in terms of persistence of vision. Efron and Lee (1971) compared predictions of moment and persistence explanations. Their results, which are consistent with a persistence model, reject any psychological-moment model in which a central pacemaker or internal clock dictates a fixed sampling period that is uninfluenced by stimulus parameters. Prior research on the psychological moment may have involved dynamic properties of sensory systems rather than any central temporal pacemaker. Breitmeyer (1984) reviewed evidence showing that "the existence of a psychological moment can be as easily explained by persistence" at peripheral levels of the visual system, and so "the notion of the psychological moment is conceptually superfluous" (p. 94). In addition, failures to link internal-clock models with the alpha rhythm of about 10 cycles/s (e.g., Treisman, 1984) weaken the frequently proposed neurophysiological basis for a fixed-duration moment of about 100 ms.

Patterson (see chapter 4, this volume) discusses relationships between psychological-moment models and recent research, which suggests that several kinds of neural persistence accompany the visual analysis of information. He concludes that although research has not adequately tested psychological-moment models, no available evidence supports the notion of a central, fixed-duration intermittency with a period of about 100 ms.

Some other research seems to reveal the operation of briefer kinds of intermittences in time-related estimates and productions, and this has led to models that hypothesize a smallest unit of psychological time, or a so-called *time quantum*. Geissler (1987), for example, reviewed analyses of various kinds of time-related response measures that suggest a time quantum with a duration of approximately 4.5 ms. Kristofferson (1980) identified a step function underlying duration discrimination in well-practiced human subjects. Based on this step function, Kristofferson concluded that the time quantum does not have a fixed periodicity; instead, it may double and halve, assuming values of about 13, 25, 50, and 100 ms. The origins of these values of the hypothetical time quantum remain obscure. At present, no research unambiguously reveals the existence of a central, neural pacemaker that may underlie the concept of a psychological moment or time quantum; there probably is none.

Psychological Present

If an event or a sequence of events lasts for more than a few seconds, people experience what most theorists call the *psychological present* or *conscious present*. James (1890), who called it the *specious present*, suggested the metaphor of "a saddle-back . . . on which we sit perched, and from which we look into two directions into time" (p. 609).

Controversy about the upper limit of the psychological present continues, especially concerning what this implies about the attention and memory systems that may underlie the phenomenon. Boring (1933/1963) said that the "conscious present can certainly include a rhythmic grouping that occupies a second or a second and a half, and that with somewhat less 'immediacy' . . . may extend to include a rhythm of a quarter or perhaps even half a minute" (p. 135). More recent evidence reveals that the upper limit of the psychological present is much shorter than this. Pöppel (1972) reported evidence suggesting a process with a period between 4 and 7 s, which he said is roughly equivalent to the time span of the conscious present. Michon (1978) concluded that the width of the psychological present is highly variable, but that the upper limit is about 7 or 8 s. Fraisse (1984) said that the psychological present averages about 2 to 3 s, with an upper limit of about 5 s. As examples of content that are part of the psychological present, Fraisse cited the perception of a telephone number, a simple sentence, or a unified rhythmic pattern. These are typical examples of content that is maintained in an activated state, or in a hypothetical short-term memory store. Block (1979) agreed that the psychological present is limited to about 5 s and suggested that this limit is related to the dynamic functioning of the short-term store.

No single temporal-judgment paradigm or method allows us precisely to measure the duration of the psychological present. To my knowledge, little or no evidence reveals any discontinuity in the experiencing of durations or intervals over the range from about 1 s through tens of seconds. The lack of any discontinuity is probably a reflection of the continuous transitions between dynamically different information-processing components, at least as far as the experiencing of a psychological present is concerned. Stated somewhat differently, the psychological present "is a highly flexible tuning process that is dynamically fitting the temporal width of the field of attention . . . to the sequential structure of the pattern of events" (Michon, 1978, p. 89).

The perception and production of rhythm, as in a piece of music or in a series of coordinated movements, depends on structural and dynamic properties of the information-processing systems underlying the psychological present (see Jones, chapter 9, this volume). If a musical or other rhythmic tempo is very slow, the limits of the psychological present may be exceeded, and a person may need to effortfully strive to synthesize what seems like a relatively nonunified piece. Thus, the experiencing of rhythm (or the lack of it) apparently involves an awareness of durations of events and of intervals between events maintained in information-processing systems involved in the construction of a psychological present (cf. Woodrow, 1951).

Memory for Temporal Order

Perhaps in interaction with human cognitive processes, information relating to the ordering of events from earlier to later gives rise to the common idea that the progression of time may be represented as a line or an arrow. The continuously integrated functioning of perceiving, remembering, and anticipating processes apparently produces a relatively automatic awareness of the successive ordering of events. This is a fundamental aspect of all temporal experiences beyond those that merely produce an experience of successiveness without the ability to discriminate temporal order. The primary psychological basis for the encoding of order relationships between events relates to the dynamic characteristics of information processing: In the process of encoding an event, a person remembers related events which preceded it, anticipates future events, or both (cf. Hintzman, Summers, & Block, 1975; Tzeng & Cotton, 1980).

Under conditions in which the same sensory-receptor areas are stimulated, trained observers can discriminate reliably (i.e., at 75% accuracy) the temporal order of two events (rather than merely discriminate two stimuli from one stimulus) only if the interval separating the events is greater than several milliseconds. Hirsh and Sherrick (1961) found a temporal-order threshold of about 20 ms for auditory, visual, and tactile stimuli. No one has yet identified a specific sensory-perceptual or cognitive process that underlies this 20-ms threshold, however; and any such threshold apparently depends on stimulus variables such as intensity, size, and position (cf. Westheimer & McKee, 1977).

If a person encodes a series of stimuli that occur with relatively long (e.g., 1 or 2 s) interstimulus intervals separating them, we can assume that order discrimination is essentially perfect at the time of the initial encoding. Several related questions then arise: How long does a person retain information about temporal order? What factors influence the accuracy of long-term temporal-order judgments? What are the implications of this level of accuracy on models of memory for temporal order and on models of memory in general?

Hintzman and Block (1971) investigated the ability of subjects to remember the approximate serial position of an event in a series of relatively homogeneous events, such as a word in series of words. Even though subjects were not forewarned about the subsequent position-judgment task, they were able to remember serial positions with a reasonable degree of accuracy. The slope of the function relating judged position and actual position serves as an index of the encoding and remembering of time-related information (see Schab & Crowder, 1988). Hintzman and Block found that this slope is greatest over the first 7-10 words in a series (a temporal span of about 35-50 s), and that the slope is more gradual, although still positive, across the remainder of the positions.

Subjects can also remember the relative spacing of pairs of related events, such as words, in a homogeneous series, as well as the distribution of repetitions of an event in each of two such series presented successively (Hintzman & Block, 1971, 1973; Hintzman et al., 1975). In addition, the accuracy of judgments of relative primacy or recency is greater for pairs of events which occurred in the initial positions in a series, a finding that mirrors the strong primacy effect seen in the slope of the position-judgment function (Marshall, Chen, & Jeter, 1989).

These findings support models in which time-related information about events and relationships among events is encoded as part of the memory of an event. Converging evidence suggests that this information, a so-called *time tag*, is contextual in nature (Hintzman & Block, 1971, 1973; Hintzman, Block, & Summers, 1973; Tzeng, Lee, & Wetzel, 1979). Contextual elements include implicit associations to an event or to other events in an episode, mood states, internal physiological cues, and conspicuous external events. The primacy effect in serial-position and relative-recency judgments, as well as the positive time-order effect in duration judgment (discussed later), suggest that changes in contextual elements occur more rapidly near the start of a new episode. Within an episode, a somewhat different process, called *study-phase retrieval*, serves to encode information concerning the relative recency of events. In this process, an event that is related in some way to a current event is retrieved, along with its contextual elements, and information concerning this retrieval is associated with the current event (Hintzman et al., 1975; Tzeng & Cotton, 1980).

Jackson (1985, 1986; see also chapter 7, this volume) has argued that, at least under certain circumstances, information-processing strategies influence the accuracy of judgments of position, recency, and similar temporal-memory judgments. For example, subjects' use of more elaborative mnemonic strategies increase the accuracy of their subsequent position judgments. In addition, subjects remember the temporal position of words in a list more accurately if the words are concrete (e.g., door) rather than abstract (e.g., truth). Further, cuing subjects to forget words impairs temporal-order judgments involving those words (Jackson & Michon, 1984). Jackson (1986) concluded that "relative order judgments may indeed reflect some automatic encoding of intrinsic order, but . . . such coding is not sufficient to enable subjects to perform more complex temporal judgment tasks adequately" (pp. 81-82).

The finding that subjects can make accurate serial-position, order, and other temporal-memory judgments even though they are not forewarned that the experimenter will ask them to do so suggests that at least some temporal or contextual information is encoded automatically. In addition, some researchers (e.g., Auday, Sullivan, & Cross, 1988) have found no influence of forewarning subjects about the forthcoming temporal-judgment task on the accuracy of subsequent serial-position and relative-recency judgments. Exactly what kinds of temporal information are encoded relatively automatically and what kinds are encoded only deliberately remains an unresolved issue. In addition, the precise role that contextual information plays in each kind of temporal judgment task must be clarified.

Memory researchers who have investigated recency and temporal-order judgments have traditionally employed a relatively simple methodology: Event *a* occurs, then an unfilled interstimulus interval, then Event *b*, and so on. However, actual relationships between events are more complex than the simple before/after relationship that is the focus of this memory research. Allen and Kautz (1985) argued that 13 primitive relationships form the basis for all knowledge about the temporal relationship between any two (or more) durations. In addition to the before/after relationship, the relationships between two durations (of events or of episodes) include: equals, meets/met by, overlaps/overlapped by, starts/started by, during/contains, and finishes/finished by. The human information-processing system probably does not automatically encode all of these relationships, so a person frequently must infer relationships among events much later than at the time that the events occurred. Future research might profitably focus on this issue.

MODELS OF PSYCHOLOGICAL TIME AS DURATION

If an event lasts for less than a few milliseconds, it seems instantaneous—without duration. If an event or episode persists for longer than a few milliseconds, people experience, remember, and may therefore be able to judge duration. A person is typically more aware of the duration of a time period if various factors influence him or her in such a way that the duration seems lengthened rather than shortened. Judgments of time periods in the range from about one-half second to a few minutes tend to be fairly veridical in that judged duration is related to actual duration in an approximately linear way, with a slope of about 1.0 (Allan, 1979; Michon, 1975, 1985). In the range from minutes to hours and days, judged time also shows this veridical function if the usual variety of events mark the passage of time. If such markers are absent, the experienced duration of a time period is somewhat shortened compared to its actual duration, as well as more variable. Experiments studying the estimation of long time periods (i.e., those on the order of hours) reveal a slight shortening of experienced duration: Subjects tend to verbally underestimate 1-hr periods and tend to produce a subjective hour that averages about 1.12 hr (discussed later, as well as in Campbell, chapter 5, this volume). Because estimates of relatively long durations may relate to the tendency of circadian rhythms to free-run with periods slightly longer than 24 hr (Aschoff, 1984, 1985), biological factors may be involved.

Experienced Duration and Remembered Duration

James (1890) asserted that duration in passing lengthens when "we grow attentive to the passage of time itself" (p. 626), whereas duration in retrospect lengthens as a function of "the multitudinousness of the memories which the time affords" (p. 624). Fraisse (1963) proposed that "direct time judgments [are] founded immediately on the changes we experience and later on the changes we remember" (p. 234). By emphasizing that psychological time involves changes, Fraisse avoided a common pitfall: As discussed later, explanations that refer to attention to time or to temporal information processing must be qualified, because time itself is not a stimulus (see Gibson, 1975). However, changes serve as referents, or cues, to use in experiencing, remembering, and judging time.

During much of this century, descriptions and interpretations of experimental findings often failed to acknowledge the distinction between duration in passing and duration in retrospect. Diverse findings that appeared to conflict merely involved different methods of obtaining temporal judgments. Even if interpretations were reasonable, descriptions of findings often did not reflect the true kind of duration judgment studied. For example, an otherwise excellent article investigating judgment of duration in retrospect is marred by the title, "Time Went By So Slowly," which suggests that the article concerns judgment of duration in passing (Loftus, Schooler, Boone, & Kline, 1987).

Most researchers recognize the importance of distinguishing between these two fundamentally different kinds of duration experiences, and some researchers have experimentally investigated the differences between the two. Experimenters study the distinction by varying instructions to subjects, using either a prospective paradigm or a retrospective paradigm (see Zakay, chapter 3, this volume). In a prospective paradigm, the experimenter tells a subject beforehand that the experimenter subsequently will ask the subject to judge the duration of a time period. Because each subject can be asked to make many such judgments for different time periods, researchers have used the prospective paradigm frequently. Hicks, Miller, Gaes, and Bierman (1977) called the temporal experience studied in the prospective paradigm "the experience of time-in-passing" (p. 443). I prefer to call it *experienced duration.* In a retrospective paradigm, the experimenter gives a subject vague instructions about the task, and only after the experimental time period does the experimenter ask the subject to judge its duration. I call the temporal experience studied in this paradigm *remembered duration.*

This distinction is intimately related to the different methods of duration judgment. When an experimenter uses a method like verbal estimation or comparison, he or she may use either a prospective or a retrospective paradigm. However, when an experimenter uses the method of production, the paradigm must be a prospective one, because the experimenter must inform the subject about the task before the subject can produce the required duration. The method of reproduction is a hybrid form of paradigm, because the experimenter may or may not inform the subject before the presentation of the to-be-reproduced duration, but the subject must make the actual reproduction prospectively.

The operational distinction between prospective and retrospective paradigms involves instructions to subjects, and so it is best to view these paradigms as influencing subjects' temporal outlook. Recent research shows that the prospective outlook and the retrospective outlook differ because of the way in which they interact with other experimental factors to influence underlying cognitive processes. For example, Brown (1985; Brown & Stubbs, 1988) found that prospective verbal estimates and reproductions are longer (and also more accurate) than retrospective judgments. Brown (1985) found little or no other difference between the two experimental paradigms, and Brown and Stubbs (1988) suggested that "a common timing process may underlie judgments under prospective and retrospective conditions" (p. 307). Nevertheless, other researchers have reported reliable differences between the two paradigms in the influence of various factors on duration judgments. Hicks, Miller, and Kinsbourne (1976) found that prospective duration judgments of a task are shortened if subjects process more information. In the prospective paradigm, it appears that subjects' allocation of attention to more difficult tasks or more complex stimuli restricts their allocation of attention to time-related information, such as contextual changes (cf. Brown, 1985).

In a retrospective paradigm, attention to time-related information has a more limited influence on duration judgments. Instead, people remember the duration of a time period by relying both on event information and on contextual information associated with the episode. If a person can retrieve a greater number of events, he or she remembers the duration of a time period as being longer (Ornstein, 1969; Vroon, 1970). However, people do not simply base retrospective duration judgments on the degree of recallability of events from the time period (Block, 1974; Loftus et al., 1987); other factors are involved. Even if people do sometimes use this kind of strategy, they undoubtedly do not attempt to retrieve all available memories of events from the time period. Instead, they probably rely on an availability heuristic—roughly, they remember a duration as being longer to the extent that they can easily retrieve a few of the events that occurred during the time period.

A slightly different proposal is that retrospective "duration judgments are based on memory for the amount of processing done" (Miller, Hicks, & Willette, 1978, p. 178). However, it is unclear how subjects are able to estimate the amount of processing done and how this kind of estimate differs from an estimate of the ease of retrieval of events. Other processes, such as a person's implicit assessment of the amount of contextual change during the duration, also play an important role (see later). However, the processes involved when subjects assess contextual change remain just as obscure as those involved when subjects assess availability of events or amount of processing.

Chronobiological Models

The normal environment affords information related to many kinds of cyclic change. Cycles involving wakefulness and sleep, light and dark, work and rest, and cold and warmth form a salient part of our lives. Even if few changes occur in a person's external environment, changing thoughts and other internal events, proprioceptive cues, and biological consequences of internal rhythms may be salient enough to afford the person an important and useful frame of reference in time.

Some chronobiologists have recently studied relationships between duration judgments and biological rhythms (see Campbell, chapter 5, this volume). More typically, though, chronobiological research investigates relationships between endogenous biological rhythms and organisms' cyclical behaviors, such as those revealed in circadian cycles of activity level, feeding, and sleeping. Their research, which uses such diverse species as honeybees, hamsters, and humans, is based on a model in which a central pacemaker (or several pacemakers) underlies and controls cyclical behaviors (see Figure 1.1).

Researchers are beginning to identify and understand the underlying brain processes, but they remain elusive (Johnson & Hastings, 1986). In some species, research has identified a specific circadian pacemaker. For example, the suprachiasmatic nuclei of some rodents apparently contain neural mechanisms which regulate behavioral cycles. As an organism's nervous system develops, cyclical external cues called *zeitgebers* ("timegivers"), such as the daily onset of light, synchronize these pacemakers. If there are no abrupt changes, once *zeitgebers* have served this function they may play a relatively minor, corrective role. Cyclical behaviors continue on an approximately 24-hr (i.e., circadian) cycle even if an organism is isolated from all exogenous changes (see Aschoff, 1984). Under conditions that are not well understood, some people who are isolated from *zeitgebers* may show an internal desynchronization of some rhythms from others, suggesting that the "circadian system consists of a multiplicity of oscillators . . . kept in synchrony by the zeitgebers" (Aschoff, 1984, p. 446).

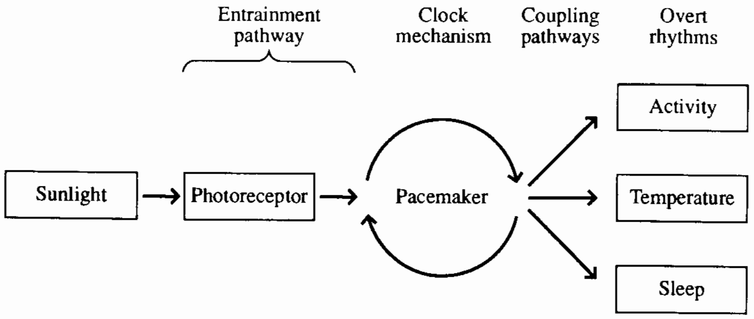

Figure 1.1. A chronobiological model of cyclical (i.e., circadian) behaviors. (After Johnson & Hastings, 1986. Adapted by permission.)

Chronobiologists typically study cyclical behaviors by seeking the physiological basis of such oscillators or pacemakers. The prototypical chronobiological model shown in Figure 1.1 seems necessary to explain the regulation of cyclical behavior. However, most extant chronobiological models are limited: They do not consider whether various strategies of the organism influence circadian rhythms. For example, a person may choose when to sleep and when not to sleep following time-zone shifts that produce so-called *jet-lag* experiences; this choice may influence overt behavioral rhythms. It may be fruitful to investigate potential ways in which such strategies modify the functioning of pacemakers that underlie biological rhythms, even if the account considers only a single category of time-related behavior, cyclical activity.

We also need to know much more about whether the pacemakers that apparently underlie circadian rhythms are involved in time-related behaviors and experiences other than overt rhythms. Fortunately, some data are now available on the relationships between experienced duration and circadian rhythms in humans. Aschoff (1985; see also Aschoff, 1984) studied people living for a period ranging from 7 days to more than 30 days in an environment that afforded no exogenous time cues. During this period, Aschoff asked his subjects to make two kinds of duration judgment. Long-duration judgments required them repeatedly to produce a 1-hr duration: They were told to signal every subjective hour (except, of course, during sleep epochs). Short-duration judgments required subjects to produce a verbally stated duration ranging from 10 to 120 s.

For present purposes, Aschoff's most important finding is that the short-duration productions were not related to the long-duration productions. Long-duration productions of a 1-hr period averaged slightly longer than 1 hr, and each person's mean production correlated positively with his or her duration of wakefulness as well as with the length of the circadian (i.e., sleep-wake) cycle. In contrast, short-duration productions were not correlated with either of these variables. Although Aschoff found considerable individual differences in short-duration productions, on the average these productions were fairly accurate (e.g., the mean production of a 10-s duration was 11.7 s and that of a 120-s duration was 116.8 s). Thus, processes involved in making short-duration judgments apparently differ from those involved in making long-duration judgments. However, the short and the long productions may have differed only because of differences in the methods used to obtain them: Long-duration productions were subject-initiated, whereas short-duration productions were experimenter-initiated. As Aschoff noted, his findings must be replicated in an experiment that uses the same method to investigate both short- and long-duration experiences.

Campbell (1986) studied the "estimation of empty time" in people restricted to an isolation unit that afforded only minimal temporal cues. In contrast to Aschoff, Campbell prohibited his subjects from engaging in activities like reading, exercising, listening to music, and so on. At various relatively long intervals (ranging from 5.2 to 23.5 hr) during a 60-hr isolation period, he asked participants to estimate the time of day. The participants verbally underestimated these intervals, and Campbell concluded that their mean subjective hour actually lasted about 1.12 hr. Lavie and Webb (1975) had found that subjects who are not strictly isolated (that is, they could engage in various kinds of activity) verbally underestimated long intervals to about this same extent. So we cannot attribute Campbell's finding that subjects verbally underestimated long intervals to the lack of activity or stimulation afforded by a monotonous environment. In addition, Campbell found that this shortening of experienced duration was about the same proportion as the mean proportion by which a person's free-running subjective day was lengthened. Campbell (chapter 5, this volume) discusses this characteristic of the human circadian system, which he calls its *sluggishness*. He also discusses the considerable variability in subjects' duration experiences, a characteristic which reveals what he calls the *sloppiness* of the circadian system.

Although biological rhythms influence psychological time, time-related experiences and behaviors involve more than the relatively simple biological processes that chronobiological models describe. Earlier in this century, however, some theorists adopting biological or biochemical models made some far-reaching claims. Consider now a historically separate, yet theoretically related, kind of model.

Internal-Clock Models

Hoagland (1933, 1966) attributed various kinds of time-related behaviors and judgments to a single mechanism: chemical processes in the brain. He called this mechanism a *master chemical clock*. The proposed mechanism is somewhat analogous to the modern conception of biological rhythms in that it relies on the notion that activity in "certain parts of the brain" (Hoagland, 1933, p. 283) underlies psychological time. However, Hoagland's chemical clock differs in other ways. First, it is more hypothetical: Hoagland was unable to identify a specific brain area, such as the suprachiasmatic nuclei, that is involved. So far, neurological evidence has failed to find Hoagland's master chemical clock, other than the processes involved in the circadian system. The circadian system, however, pertains to longer time periods than the seconds-to-minutes periods to which Hoagland's model most directly applies. Second, Hoagland's model contains no notion of *zeitgebers*, or entraining stimuli. Third, the explanatory burden of this model lies mostly outside the domain of cyclic behaviors. Instead, Hoagland's model attempts to explain aperiodic duration experiences, such as the experience of time-in-passing over brief periods.

Without speculating about a possible biochemical or neural basis, Treisman (1963) extended Hoagland's notion by proposing a model of what he called the *internal clock* (see Figure 1.2). In this model, a pacemaker produces a regular series of pulses, although the pulse rate increases as an organism's specific arousal level increases. A counter records the number of pulses that arrive at a given point, and the result is entered into a store or into a comparator mechanism. A verbal selective mechanism (a long-term memory store containing verbal labels, such as *20 sec*, *1 min*, etc.) assists in retrieving useful information from the store.

Treisman (1984) recently attempted to determine whether the frequency of this hypothetical pacemaker is related to the well-known alpha rhythm. The alpha rhythm is frequently mentioned as a possible source of (or reflection of) the kind of pacemaker involved in a hypothetical internal clock. Treisman recorded EEGs of subjects while they produced 4-s durations in a darkened cubicle. His data failed to support the notion that arousal, which is presumably reflected in alpha frequency, is correlated with the frequency of the hypothetical pacemaker. These data also do not support the notion that a common pacemaker may influence both the alpha-rhythm generator and the frequency of the hypothetical pacemaker in an internal-clock system. In short, this evidence offers no empirical support for any relatively simple internal-clock model, and there is no known neurophysiological basis for the components of Hoagland's (1933) and Treisman's (1963) models. Furthermore, it is questionable whether this descriptive model is needed to explain temporal behaviors and experiences.

Some contemporary behavioral psychologists, especially those who collect the kinds of data needed to make inferences about cognitive processes in animals, have also explored internal-clock models. They

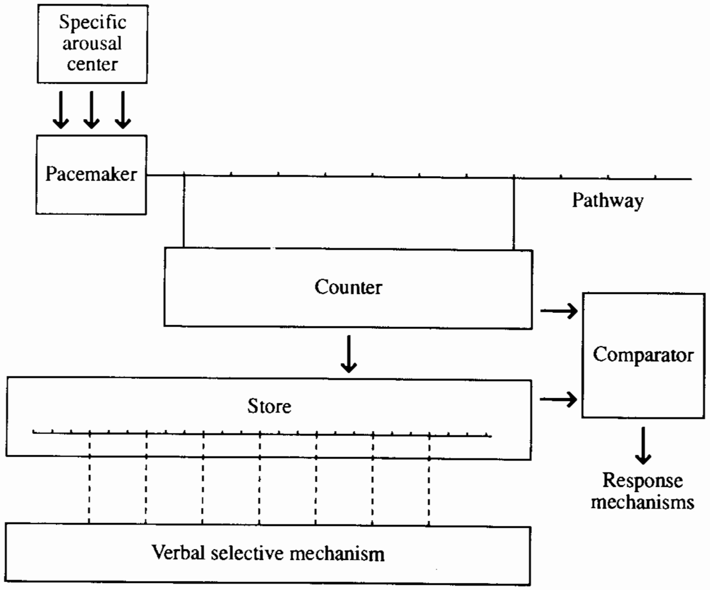

Figure 1.2. A model of a hypothetical internal clock. (From Treisman, 1963. Reprinted by permission.)

typically investigate behavioral responses of animals such as pigeons and rats during relatively short time periods (e.g., seconds to minutes). The general finding is that animals are sensitive to different interval schedules of reinforcement. Many behavioral psychologists propose that interval-schedule responding relies on an event-independent timer, or internal clock.

Figure 1.3 illustrates a general behavioral model of this hypothetical internal clock (see, for example, Church, 1984; Roitblat, 1987, and chapter 6, this volume); note that it is strikingly similar to Treisman's (1963) model (see Figure 1.2). It assumes that the internal-clock mechanism consists of a pacemaker, a switch, and an accumulator. The pacemaker, operating somewhat like a metronome, generates more or less regularly spaced pulses, as in Treisman's model. This assumption of the model fits nicely with the finding that in various species subjective duration and actual duration are apparently linearly related. At the onset of a relevant external timing signal, the switch engages and the accumulator begins to count pulses. The switch is included in the model to handle the finding that an interrupted timing signal may stop the accumulation of pulses from the pacemaker, as revealed by temporally displaced responding. This implies that the internal clock functions like a stopwatch. (This feature represents a difference between this model and Treisman's model, which has no counter-stopping mechanism.) A reference memory retains information about the approximate number of pulses that elapsed before past reinforcement. A working memory holds the current total pulse count. The response rate on an interval schedule increases in probability as a comparison (by the comparator mechanism) of working memory and reference memory reveals a similar count of pulses.

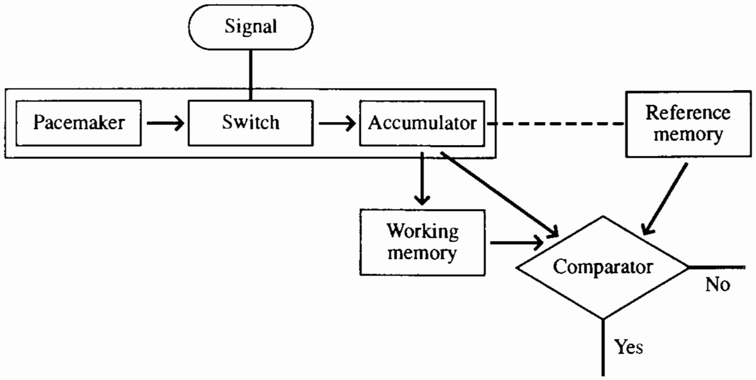

Figure 1.3. A model of time-related behavior in animals. (From Church, 1984. Reprinted by permission.)

Because this timing scheme can time various kinds of signals, it is somewhat flexible. However, the model is limited in the sense that it does not take into account other potentially important factors, which are more prominent in humans than in other animals. For example, activities (such as strategies) of an organism during a time period influence its time-related behaviors, but this model is silent on that issue. Evidence suggests that children, for example, use an "external clock" to time an interval; that is, they engage in various repetitive movements that take an appropriate amount of time while they wait for reinforcement (Pouthas, 1985).

A serious question about all internal-clock models concerns whether they can be generalized to handle evidence on human timing and temporal judgment. These models seem unable to explain why cognitive kinds of factors (e.g., strategies) influence temporal behavior and experience. No existing internal-clock model includes a mechanism whereby these factors influence the basic functioning of the hypothetical pacemaker; indeed, the pacemaker in these models is relatively autonomous (immune to external influence). In addition, these models focus mainly on experienced duration (that is, prospective interval timing). Thus, they differ considerably from cognitive-process models that can easily handle remembered duration and that emphasize how controlled strategies interact with other factors in complex ways to influence temporal experiences. Internal-clock models seem best suited to handle relatively simple relationships, such as that between body temperature, arousal, and response rate. Thus, internal-clock models propose what may be an oversimplified view of the complex set of processes that underlie psychological time.

Related to this is the problem of why human duration judgments are sometimes so inaccurate, especially for an organism that is said to possess an internal clock. For example, Loftus et al. (1987) found that the mean remembered duration of a 30-s videotape was about 150 s. Cognitive models, which propose that a variety of different factors influence remembered duration, can explain the inherent inaccuracy of human duration judgments more convincingly than can internal-clock models. An alternative view is that people make such inaccurate duration judgments only when they must "translate" a duration experience into a conventional verbal unit (e.g., "It was about 142 s"). If, instead, they may produce temporal judgments by responding nonverbally, as other animals do, their interval timing may be much more accurate (see, for example, Slanger, in press).

In short, internal-clock models proposed by behavioral psychologists investigating interval timing in nonhuman animals seem limited. Most cognitive psychologists agree that these models are incomplete, and they think that other models of time-related behavior and experience are more valid. Animal models are interesting, but unless they consider the role that cognitive factors play, we probably cannot generalize them very easily to human psychological time. In this regard, Richelle and his colleagues (e.g., Richelle & Lejeune, 1980; Richelle, Lejeune, Perikel, & Fery, 1985) have made considerable progress: They have done comparative research involving several species, including humans, and they have included a role for cognitive factors. Perhaps as a result, Richelle et al. (1985) were able to pose a provocative question: "Why not admit that there are as many clocks as there are behaviors exhibiting timing properties?" (p. 90).

Cognitive psychology is not without its own internal-clock models, however: Some researchers studying human movement timing have also proposed internal-clock models. Lashley (1951) proposed that practiced movement sequences are structured as individual elements organized into chunks that are executed as part of a what he called a *motor program* for the action sequence. Because Lashley proposed that a motor program is executed without the need for feedback, the program needed some sort of internal-control process for timing the elements of the program. Researchers have searched for a common mechanism, such as an internal clock, which is able to stabilize motor programs in the face of changes in states of the performer, changes in contextual stimuli, changes in equipment or instruments used for the performance, and so on. They have had some successes. However, the important question of how movement sequences are timed is still largely unresolved, as is the question of whether recourse to an internal-clock mechanism is needed (see Summers & Burns, chapter 8, this volume).

Attentional Models

Several theorists have proposed attentional models of psychological time in which terms like *attention to time* and *temporal information processing* play a major explanatory role (e.g., Hicks et al., 1976; Thomas & Weaver, 1975; Underwood & Swain, 1973). In this section, I review some of the evidence relating to these attentional models, and I suggest several sources of inadequacy in the elaboration of them.

Thomas and his colleagues (Thomas & Brown, 1975; Thomas & Weaver, 1975) developed and tested a mathematical model concerning how attentional allocation influences perceived duration. This model has the benefit of being an explicitly formulated and, thus, easily criticized attentional model of psychological time, which is why I am focusing on it here. The model may be expressed as the functional equation: $\tau(\mathrm{I}) = a\,\mathrm{f}(t,\mathrm{I}) + (1 - a)\,\mathrm{g}^*(\mathrm{I})$. The basic notion of the model is that the perceived duration (τ) of an interval containing certain information (I) is monotonically related to the weighted average of the amount of information encoded by two processors, a temporal information processor, or timer $[\mathrm{f}(t,\mathrm{I})]$ and a nontemporal information processor $[\mathrm{g}^*(\mathrm{I})]$. Attention is divided between the two processors, which function in parallel. Perceived duration is weighted (with probability parameter a) to optimize the reliability of the information that each processor encodes, because as more attention is allocated to one processor, the other becomes more unreliable. That is, as a approaches 1, the subject encodes more temporal information, and as a approaches 0, the subject encodes more nontemporal information. To the extent that little stimulus information occurs during the to-be-judged duration, more attention is allocated to temporal information, and f(*t*,I) is more heavily weighted; to the extent that considerable information occurs, more attention is allocated to nontemporal information, and g*(I) is more heavily weighted.

Thomas restricted the range of applicability of this model to duration judgments of stimuli presented for less than 100 ms, and it is not surprising that his data generally fit the model. Moreover, Michon (1985) stated that this model provides a good generic model of temporal information processing, even that involving much longer time periods. I have some reservations about this, because the extension of this model to longer time periods is post hoc, and some data seem to reject this extension of the model (e.g., Michon, 1965; Vroon, 1970). Consider Vroon's experiments, which investigated how an information-processing task influences the remembered duration of a 60-s time period.

In one experiment, Vroon presented subjects with two time periods, each of which contained a series of high- and low-pitched tones, and their task was simply to attend to the tones. One time period was filled with more stimuli than the other: Subjects heard 60 rather than 30 tones. Vroon found that subjects remembered the duration of the time period containing more tones as being longer. Along with other models that I discuss later, Thomas' model can explain this finding. It assumes that if a person encounters a greater amount of information, he or she allocates greater attention to the processing of this nontemporal information [g*(I)], and remembered duration lengthens as a result.

In another experiment, Vroon required subjects to respond actively to the presented information; they had to classify each tone as being either low-pitched or high-pitched and respond appropriately. These results reveal the opposite effect: Remembered duration was shorter if subjects processed a greater amount of information. In this case, the remembered duration of the time period could not have been based on nontemporal information [g*(I)], or the finding would have been the same as before. It must, therefore, have been based on temporal information [f(*t*,I)]. Taken by itself, this explanation seems reasonable, because a person should be able to encode more temporal information under conditions of reduced information-processing demands. However, it is incorrect to assume that subjects encoded more reliable temporal information in Vroon's second experiment than in his first, because in the second experiment subjects performed a more attention-demanding information-processing task. Thus, the explanations that Thomas' model provides are post hoc and unconvincing.

Another difficulty is that this kind of model does not take into account changes in arousal level or variations in level of alertness attributable to circadian rhythms and other biological factors. It assumes that there is a constant pool of attentional resources. A more general model more along the lines of Kahneman's (1973) resource model of attention appears to be needed. Kahneman proposed that arousal influences the total attentional resources available to be allocated at any moment to meet information-processing demands. Thus, temporal information processing is influenced not only by characteristics of the stimulus information that a person is processing, but also by momentary arousal level and, hence, total available resources. We need this kind of amendment to Thomas' model to account for findings that increased alertness, such as when a person is under the influence of stimulants like methamphetamine, lengthens duration experience (Frankenhaeuser, 1959).

Thomas' model is also too passive: Stimulus information alone determines the allocation of attention, and strategies are not involved. Some recent research focuses on information-processing strategies (Jackson, chapter 7, this volume; Michon, 1989; Michon & Jackson, 1984). A person selects and uses particular strategies, such as kinds of attentional deployment and mnemonic involvement, depending on the ways in which he or she interprets and approaches an information-processing task. In spite of these problems, Thomas' model has played an important role in guiding research and theories on psychological time.

Consider another attentional model. Underwood (1975) proposed that duration experience is positively related to the degree of attentional selectivity that an information-processing task requires. Some evidence supports this notion. For example, Underwood and Swain (1973) found that subjects remembered as being longer in duration a prose passage which presumably required greater attentional selectivity for its analysis than one that presumably required less attentional selectivity. Other studies, however, have not found the expected influence of attentional manipulations on remembered duration (Brown, 1985; Gray, 1982). The possible ways in which a person's attentional selectivity influences the remembered duration of a time period are unclear. Attentional selectivity probably interacts in complex ways with task demands and information-processing strategies. To explain some other findings, Underwood (1975) also mentioned the amount of attention a person pays to time itself. Some experiments on experienced duration support the claim that this factor is important (see Block, George, & Reed, 1980). However, this explanation lacks specificity (see later).

A theoretical problem with attentional models of psychological time, including both Thomas' (Thomas & Brown, 1975; Thomas & Weaver,

1975) model and Underwood's (1975; Underwood & Swain, 1973) model, lies in the similar concepts of attention to time and temporal information processing. Several theorists have attempted to explain the finding that experienced duration is longer than remembered duration (e.g., Brown, 1985) by saying that in a prospective paradigm a person attends to the passage of time itself and that this kind of attentional deployment lengthens duration experience. This explanation is vacuous without some additional specification of the information to which a person attends when he or she deploys attention in this way. The term *time perception* is widely used to refer to processes involving psychological time (e.g., Allan, 1979; Woodrow, 1951). Gibson (1975) stressed that the perception of time is an insoluble problem: He said that "there is no such thing as the perception of time, but only the perception of events and locomotions" (p. 295). Thus, terms like *attention to time* and *temporal information processing* are unacceptably vague without an accompanying specification of time-related attributes to which a person is attending (see Zakay, chapter 3, this volume). Along these lines, Michon and Jackson (1984) proposed that the principal attributes that qualify as temporal information are the simultaneity and order of events. In addition to these external stimulus attributes, temporal information probably also includes changes in internal attributes, including proprioceptive information, moods or emotions, kinds of cognitive processes, and so on. What, then, does it mean to attend to time itself? The answer may be that it involves an awareness of changes (or the lack of such changes) in events or cognitions occurring during a time period. This awareness seems to be characteristic of a person adopting a prospective outlook on an ongoing episode.

Memory-Storage Models

Some early philosophers who speculated about time-related experiences realized that time is intimately connected to memory processes. Aristotle (c. 330 B.C.) said that "only those animals which perceive time remember, and the organ whereby they perceive time is also that whereby they remember" (McKeon, 1941, pp. 607-608). More recently, cognitive psychologists have proposed a number of different memory models in attempts to explain duration experiences.

Ornstein (1969) was an early critic of internal-clock models. He obtained considerable evidence suggesting that these models cannot parsimoniously explain why information-processing activities, such as the ways in which a person encodes information, strongly influence remembered duration. Ornstein argued that remembered duration is a cognitive construction based on what he called the *storage size* in memory taken up by encoded and, later, retrievable stimulus information. If a person encodes more stimuli during a time period, or if the person encodes the stimuli in a more complex way, the experience of duration lengthens. Ornstein also provided evidence that information supplied after a time period influences remembered duration, presumably by influencing the accessibility of stored information.

It appears that the storage-size model is seriously flawed. Ornstein reported that people remember the duration of a time period as being longer if they had viewed a more complex figure than if they had viewed a less complex figure. Subsequent experiments challenge this fundamental prediction of the storage-size model and clarify the way in which complexity influences remembered duration (Block, 1978). Subjects do not necessarily judge a sequence of stimuli as being longer in duration if the individual stimuli are more complex than if they are less complex. However, they do remember a more complex sequence of stimuli (i.e., one in which a natural sequence of stimuli is randomized) as being longer in duration than a less complex sequence. These data suggest an alternative explanation of Ornstein's findings on effects of stimulus complexity: Instead of storage size per se, the variability of a person's encodings (i.e., the cognitive context) may be the critical factor, and subjects encode a greater number of different interpretations of a more complex stimulus than of a less complex stimulus. In other words, changes in cognitive context are critical, not the inherent complexity of individual stimuli.

In another experiment, Ornstein found that information provided to subjects after an information-processing task influences the remembered duration of the task. In contrast, Predebon (1984) reported that subjects comprehend and recall a prose passage better if they receive prior thematic information, but prior thematic information does not influence the remembered duration of the passage. Predebon interpreted these findings in terms of a contextual-change model (see later): Remembered duration is based on the overall amount of change in cognitive context during a time period, not on the size of the storage space occupied by memories of stimulus events.

Ornstein proposed the storage-size model during a period in which cognitive psychology was using the metaphor of the mind as programs running in a digital computer. Even though the storage-size model had several advantages over internal-clock models, it is based on an implausible memory metaphor. Compared to memory processes in digital computers, human memory functions in a more interconnected way, reflecting a continual reorganization of previously encoded information. As Estes (1980) succinctly put it: "Human memory does not, in a literal sense, store anything; it simply changes as a function of experience" (p. 68). Ornstein's storage-size model cannot easily handle findings revealing the importance of changes in contextual factors. I now discuss these experiments, along with resulting memory-change models.

Memory-Change Models

More than a century ago, the physicist Mach (1883/1942) said that "time is an abstraction, at which we arrive by means of the changes of things" (p. 273). James (1890) agreed, saying that "awareness of change is . . . the condition on which our perception of time's flow depends" (p. 620). Guyau (1890/1988) outlined a contemporary-sounding view in which, among other things, cognitive factors influence time judgments. Guyau's factors included the number of events, the number of differences among them, the amount of attention paid to them, and various associations to the events. As the middle of this century approached, internal-clock models became influential, and cognitive models receded into the background. One exception was the work of Frankenhaeuser (1959), who conducted a series of important experiments in which she asked subjects to estimate durations. Frankenhaeuser concluded that the amount of mental content during a duration, which several factors influence, is a critical determinant of duration experience. Fraisse (1963) concluded that "psychological duration is composed of psychological changes" (p. 216). Gibson (1975) said that "external stimuli . . . provide a flow of change, and it is this we perceive rather than a flow of time as such" (p. 299).

Block and Reed (1978) reported evidence suggesting that important changes during a time period do, indeed, influence the remembered duration of it. These changes include those in variables such as background stimuli, interoceptive stimuli (e.g., posture, temperature, nausea), and the psychological context—that is, "what the subject is thinking about," or "the internal monologue" (Bower, 1972, p. 93). Specifically, Block and Reed found that subjects remembered a duration as being longer to the extent that changes in process context had occurred. Process context changes occur when a person employs different kinds of cognitive processes as he or she engages in various tasks or strategies of encoding during a time period. This kind of information is apparently encoded as an integral part of the memory representations of stimulus events. Block and Reed proposed what they called a *contextual-change* model of remembered duration. According to this model, remembered duration involves a cognitive reconstruction based on retrieving contextual information that is stored as an integral part of the

memory encodings of events, rather than a reconstruction based on retrieving stimulus information per se. The greater are the encoded and retrievable contextual changes, the longer is the remembered duration of a time period.

Process context changes are not the only kind of change that influence remembered duration. Block (1982) investigated environmental context as another potentially salient source of contextual changes. Subjects' previous experience in a particular environment (a room containing an experimenter, various objects, and so on) shortened the remembered duration of a subsequent time period spent in that environment. One interpretation of this finding is that more contextual changes occur during a time period spent in unfamiliar surroundings. This explanation is supported by the additional finding that if the encoding of environmental context is different in some way during a second time period, the relative duration of that time period lengthens. Further, different kinds of contextual factors do not simply produce additive effects on remembered duration (Block, 1982, Experiment 3). Instead, subjects apparently assess remembered duration by integrating the combined influence of different kinds of factors; and in doing so, some factors are more salient than others.

Several additional tests of the contextual-change model support only one of two versions of it. One version offers a rather mechanistic explanation: It says that the critical factor is the number of different contextual associations connected with the memory traces of stimulus events. (This interpretation resembles the complexity-of-coding notion of the storage-size model.) This contextual-association version of the model cannot explain why subjects remember an imagery task that maximizes the number of varied contextual associations as being shorter, rather than longer, than an imagery task that minimizes the number of varied contextual associations (Block, 1986). This finding contradicts the notion that the encoding of varied contextual associations is critical. Another version of the model says that an overall change in context from a preceding duration to the to-be-judged duration, which is encoded during the to-be-judged duration, is the critical factor underlying remembered duration. This version, which is less specific than the contextual-association version, could not be rejected. Remembered duration was influenced by an interaction between performance of a preceding imagery task and performance of a specific kind of imagery task during the to-be-judged duration. Thus, any contextual-change model must accommodate interactions of contextual factors.

A person's processing activities (e.g., encoding strategies) interact with the kind of information-processing task in which the person is engaged. This interaction in turn influences the remembered duration of the task (Block, 1986). Consider Michon's (1965) and Vroon's (1970) findings on the influence of information-processing on duration judgments, which are embarrassing both to attentional models (e.g., Thomas & Weaver, 1975) and to storage-size models (e.g., Ornstein, 1969). As noted earlier, Vroon found that the way in which the amount of presented information influences remembered duration depends on whether subjects actively process the information. The contextual-change model offers an explanation for this interaction: For each item which a person must actively process, correspondingly less attention is available for a subject to encode contextual changes occurring during the duration. If a person must make a greater number of overt decisions about presented information, he or she encodes and remembers fewer contextual changes.

The contextual-change model predicts a positive time-order effect in retrospective judgments of duration, especially if fairly long time periods and a comparative duration-judgment task are used. A positive time-order effect is the finding that (with all other factors equal or counterbalanced) subjects remember the first of two equal time periods as being longer than the second (for reviews, see Block, 1982, 1985a). More generally, a positive time-order effect is also revealed in longer retrospective judgment of durations presented earlier in a series of several durations (see Brown & Stubbs, 1988). The contextual-change model says that a subject encodes more changes in contextual elements during a relatively novel experience, such as during the first of several durations, and that this lengthens remembered duration. Two additional findings support the notion that contextual changes influence the positive time-order effect. The effect is eliminated if the environmental context prevailing during the second of two durations is different from that prevailing during the first (Block, 1982). The effect is also eliminated if changes in emotional context that would ordinarily occur during the first duration occur instead during a preceding time period (Block, 1986). Note that the positive time-order effect is somewhat counter-intuitive. For example, Ornstein's (1969) storage-size model predicts just the opposite, a negative time-order effect attributable to "items dropping out of storage" (p. 107). Although Ornstein did not mention it, some of his data seem to reveal a positive time-order effect rather than a negative one (see Block, 1986).

A difficulty with the contextual-change model is that its explanations tend to be circular, because it does not propose any independent way of measuring the amount of change in cognitive context. (There is, similarly, no independent way of measuring storage size in the storage-size model.) However, recent studies of components of event-related potentials (brain-wave changes accompanying the processing of events) suggest a possible psychophysiological measure. Some researchers have hypothesized that the P300 (also called P3) component reflects a process called *context updating* (Donchin & Coles, 1988), although this hypothesis is a controversial one (see Verleger, 1988 and the commentaries on Donchin and Coles' article).

Another problem with the contextual-change model is that it is difficult to ascertain which specific cognitive processes are involved when a person remembers the amount of contextual change during a time period. This problem is like that encountered in attempting to ascertain the specific processes involved when a person assesses the amount of attention allocated to some information, the amount of information processed by the person, or the amount of storage space required by some information.

MODELS OF PSYCHOLOGICAL TIME AS TEMPORAL PERSPECTIVE

Temporal perspective involves ways in which people view and relate to issues concerning past, present, and future. These phenomena are uniquely psychological in that modern physics has no need for the conception of time's passage from past to present to future (Fraser, 1987). The fundamental time-related equations of physics concern only the relative ordering of events (i.e., earlier/later). As noted earlier, people tend to view time as a dimension or continuum evolving from the past through the present and into the future. Alternatively, the common perspective is that of a succession of events approaching from the future, being experienced in the present, and receding into the past.

From a cognitive viewpoint, the psychological present usually consists of a mixture of remembrances of past events, responses to present events, and anticipations of future events. However, little or no cognitive work addresses how temporal perspective may be derived from the psychological present (but see Michon, 1978).

Issues concerning temporal perspective and its vicissitudes arise from several different sources. Questionnaire research reveals that beliefs about the relative importance of the past, the present, and the future vary considerably between individuals (e.g., Block, Saggau, & Nickol, 1983-84). Temporal perspective apparently varies more between individuals from different countries than between individuals from the same country (Block, Buggie, & Saggau, in preparation). Cross-cultural investigations are an important, if rather under-utilized way, to study temporal perspective.

Perhaps the most important work on temporal perspective is that which investigates the ways in which psychiatric disorders disrupt or otherwise modify an individual's temporal perspective. Melges (chapter 11, this volume) reviews this fascinating literature and theorizes about the implications for normal temporal perspective.

Literature on altered states of consciousness, such as those induced by techniques of hypnotism or concentrative meditation, reveals additional information about the range of potential temporal perspectives (for a review, see Block, 1979). As people experience altered states of consciousness, they report unusual kinds of experiences. In some states, the construction and maintenance of temporal perspective seems suspended, and people concurrently report a quality of temporal experiencing that is best characterized by the term *timelessness*. Although experiences of timelessness are usually somewhat ineffable, one recurring kind of description is that they involve an altered mode of temporal perspective in which "divisions of time, including divisions into past, present, and future, are [experienced as] . . . illusion. Events do not 'happen' or 'occur,' they 'are'" (LeShan, 1976, p. 92). One explanation of this kind of phenomenon is that processes involving working or activated memory, which ordinarily encode the current context in which ongoing events are occurring, do not function in the way that they usually do. In other words, a person may experience timelessness if the momentary environmental or psychological conditions prevent him or her from constructing a cognitive context in which to interpret an episode. Under these conditions, a person does not maintain the usual assumptions about time and reality, and attention diverts from external events to internal processes. A person experiences and remembers the duration of such a time period only with great difficulty. This kind of experience represents an interesting limiting case for cognitive models of psychological time, especially those involving the formation and maintenance of temporal perspective.

A GENERAL CONTEXTUALISTIC FRAMEWORK

A general contextualistic framework provides a useful summary of various important factors that influence psychological time, many of which I discussed in this chapter and in other recent reviews (Block, 1985a, 1985b, 1989a, 1989b). This framework is called *contextualistic* because it emphasizes factors surrounding an event or episode which

influence an organism's encoding of, conceiving of, and responding to the event or episode. The framework includes four kinds of factors that influence psychological time.

The four factors, or clusters of variables, are: characteristics of the time experiencer, contents of a time period, activities during a time period, and time-related behaviors and judgments. Important characteristics of the time experiencer include such variables as species, sex, personality, interests, temporal perspective, and previous experiences. The contents of a time period include various attributes of events, such as their number, complexity, modality, duration, and so on. Although an organism may attend primarily either to external events or to thoughts, experience is always a mixture of activated representations of both external and internal events. An organism's activities during a time period range from relatively passive nonattending to external events through more actively controlled processes, such as strategies in which a person engages in the process of acquiring information. The kinds of activities in which an organism engages are mainly influenced by previously learned strategies, by instructions that an experimenter provides, and by the events that occur during a duration. Finally, changes in time-related behaviors occur as an experimenter or an environment demands various temporal judgment or estimation–simultaneity, rhythm, order, spacing, duration, and so on.

None of these factors operates in isolation from the others: If one factor changes, it interacts with the other factors in different ways. Because many experiments on psychological time study only one or two factors in relative isolation, the findings of these studies tell us relatively little. The resulting models can handle only those factors that theorists have chosen to investigate, and only under relatively special conditions.

This general contextualistic framework helps to clarify experimental findings and process models, especially by highlighting what they are omitting (see Block, 1989a). I emphasize that this framework is a descriptive, or heuristic, one; it is neither a process model nor a formal (e.g., mathematical) model. A limitation is that this framework does not reveal which factors or which interactions are the more important ones. Another problem is that this framework does not precisely indicate the ways in which the factors interact. Many of the interactions remain relatively obscure and not well understood. A more complete understanding of the complexities of psychological time will be possible only after researchers have experimentally investigated the complex interactions among the factors and generated more specific, process models. The main contribution of this framework is to emphasize the factors that may be needed in any relatively complete model of psychological time.

SUMMARY AND CONCLUSIONS

This chapter evaluated models concerning several aspects of psychological time—as succession, as duration, and as temporal perspective.

Experiences of successiveness, or the primary psychological encoding of order relationships between events, involves dynamic information-processing characteristics: In the process of perceiving and encoding an event, a person remembers related events which preceded it, anticipates future events, or both. The notion of a fixed-duration psychological moment arose largely from experiments that are now thought to involve visual persistence; the available evidence does not support the notion of a central pacemaker or internal clock. Similarly, the experiencing of a psychological present is probably related to the temporal dynamics of short-term, or activated, memory. Some time-related information about events and relationships between events is apparently encoded automatically, whereas other information is only encoded deliberately.

The experience of duration in passing may differ from that in retrospect. Experienced duration depends on variables such as the amount of attention to temporal information, whereas remembered duration involves contextual changes encoded in memory. Models of psychological time as duration vary considerably. Chronobiological models typically attempt to explain diverse cyclical behaviors by seeking the physiological basis of a pacemaker or pacemakers in the brain of the organism. Some psychologists have also explored the notion of a pacemaker—a collection of brain processes that generates a series of pulses or other cyclical marker events which may underlie temporal experiences. However, these internal-clock models seem unable to explain the diverse ways in which cognitive kinds of factors influence temporal behavior and experience. As an alternative, many cognitive psychologists believe that the experience of duration is related to the storage size in memory of information that occurred during a time period. Another interesting class of model is that which emphasizes the deployment of attention, including the concept of attention to temporal information. However, changes in cognitive context during a time period influence remembered duration, and a contextual-change model provides a better account of recent evidence than do storage-size and attentional models.

Phenomena of temporal perspective involve experiences and conceptions concerning the past, the present, and the future. Temporal perspective differs between individuals, and it often changes radically when a person experiences altered states of consciousness, including those related to psychiatric illnesses. At present, no comprehensive model is able to account for the formation and maintenance of temporal perspective.

A general contextualistic framework summarizes interactions of four kinds of factors that influence psychological time: characteristics of the time experiencer, contents of the time period, the person's activities during the time period, and the person's time-related behaviors and judgments. Although this framework clarifies experimental findings and process models, it does not indicate the precise ways in which the factors interact.

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