TIME AND HUMAN COGNITION
A Life-Span Perspective
I. Levin and D. Zakay (Editors)

CHAPTER 9

RICHARD A. BLOCK

Experiencing and Remembering Time: Affordances, Context, and Cognition

1. INTRODUCTION

Experimental psychology originated in the late 1800s, and ever since then psychologists have investigated the nature of time-related experiences and behavior. The many empirical studies that researchers have conducted reveal that the psychology of time is extremely complex. No simple theory can adequately handle the variety of temporal behaviors and experiences that have received attention. Recently, I have been exploring the heuristic value of a contextualistic model of temporal experiences, and this chapter uses it as an organizing tool to view some of the diverse experimental findings and theories, focusing especially on duration experiences.

Several previous articles (Block, 1985a, 1985b, in press) have explained the origins and development of this general contextualistic model. I begin by summarizing the model.

2. A CONTEXTUALISTIC MODEL OF TEMPORAL EXPERIENCE

The general contextualistic model holds that four kinds of factors interact to influence temporal experiences. The model may, therefore, be diagrammed as a tetrahedron (Block, 1985a, in press). The model adapts one that Jenkins (1979) used in his summary of research on levels of processing. Bransford (1979) used a similar model to describe processes involved in learning, understanding, and remembering. Each of the four factors is a cluster of variables which interact with each of the other factors to influence temporal experiences. Variables grouped within the same factor for the sake of simplicity also interact in various ways.

The model helps in classifying experiments on the psychology of time, most of which manipulate only one or two of these factors. It also reveals differences among theories, as well as the limitations of any theoretical formulation (Block, in press). I first summarize this classification of factors. Then I consider in detail some of the more specific variables and processes involved in temporal experiences.

One factor is the kind of temporal behavior under consideration. Experiments investigate this factor by requesting different kinds of temporal judgment, or estimation—judgment of simultaneity, successiveness, rhythm, order, spacing, duration, and so on. Further, researchers use a range of different methods to study each of these kinds of temporal judgment. Another factor is the characteristics of the time period which a person experiences and, perhaps, also evaluates and judges. This includes the absolute duration of the time period, as well as various contents—events, whether external or purely cognitive, that occur during it. Characteristics of events include their number, their complexity, their modality, and so on. Another factor is the characteristics of the experiencer. Within an individual, the variables included here range from fixed and unchanging (such as species and sex) to somewhat changeable (such as personality and interests) to relatively transient and changeable (such as previous experiences in an experimental setting). The final factor is activities during the time period. A person may engage in various activities, ranging from relatively effortless nonattending through relatively effortful information-processing strategies. Kinds of activities are primarily influenced by the events occurring during a duration, instructions provided by an experimenter, and previous learning of strategies.

A complete understanding of any kind of temporal experience is possible only if we consider complex interactions among all of these factors. The contexture of psychological time, according to this model, is a complex, multifaceted pattern. None of the factors ever operates in isolation from the others. When one factor changes, the precise nature of the interactions of the other factors also changes. In practice, however, most experiments on the psychology of time manipulate only one or two of these factors. If we consider lower-order interactions we get a somewhat limited, but nevertheless useful, understanding of a particular kind of temporal experience.

With this in mind, I now review evidence showing some ways in which each of the factors influences temporal experiences.

3. TEMPORAL JUDGMENT METHODS

3.1 Judgment of Simultaneity and Successiveness

Awareness of the successiveness of events is a fundamental aspect of temporal experiences. Early observations suggested that humans may experience successiveness, rather than simultaneity, if the interval between two brief auditory events is at least 2 ms (see James, 1890; Hirsh, 1959). However, relatively accurate temporal-order judgments apparently require that an interval between two events be at least 20 ms, and this is the case regardless of the modality of the events (Hirsh & Sherrick, 1961).

3.2 The Psychological Present

A rather compelling experience of a psychological present occurs whenever a person perceives a sequence of events lasting a few seconds. James (1890) asserted that people are "constantly conscious of a certain duration—the specious present—varying in length from a few seconds to probably not more than a minute" (p. 642). More recent theorists put the upper limit of this experience at about 5–10 s, with the clear implication that it is a phenomenon attributable to the dynamics of activated, or short-term, memory. Fraisse (1963) commented that this psychological present enables us to "perceive units of change which ... are elements from which we construct the unity of our whole psychological life" (p. 98). There is no single method that enables a precise measurement of the psychological present; however, experiences of rhythm critically depend on the tempo of the sequence of events—if the rate is too slow, a person

will not apprehend a rhythmic grouping. Thus, experiences of rhythm seem to involve an awareness of durations of events and of intervals between events in the psychological present.

3.3 Spacing, Order, and Position Judgments

Research using longer intervals shows that people are able to judge fairly accurately the temporal positions of occurrences of a repeated event (Hintzman & Block, 1971). A relatively automatic retrieval of previous occurrences by a subsequent repetition might mediate these judgments (Hintzman & Block, 1973). The automatically retrieved information about a previous occurrence of an event includes contextual information, such as the person's feelings or thoughts at that time, as well as the modality, approximate recency, and other features of the occurrence. A person may then judge the spacing of a repeated event by relying on this contextual information.

The same kind of contextual information may also allow a person to judge the order, or temporal position, and the spacing of unrelated events (e.g., Hintzman, Block, & Summers, 1973; Hintzman, Summers, & Block, 1975). These judgments are considerably less accurate, however, and they are heavily influenced by a person's activities during the time period—that is, by controlled strategies of information processing. Jackson (1985, 1986) found that individual differences in the accuracy of subsequent position judgment of words in a temporal series are related to the mnemonic strategies which different subjects had used. Elaborative kinds of rehearsal, such as combining words to form a connected story, are related to fairly accurate temporal-position judgment; whereas simple kinds of rehearsal, such as repeating single words, are related to less accurate position judgment. In addition, temporal-order judgment is more accurate following semantic-feature processing of events than following mere physical-structure processing. Jackson and Michon (1984) also found that position judgments are more accurate for concrete than for abstract word-lists, and cuing subjects to forget words impairs subsequent temporal-order judgments involving those words. 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).

3.4 Duration Judgment

Outside of the laboratory, there are several major ways by which a person typically expresses duration judgments. Perhaps the most common type of report is simply that an expected event seems like it is taking "forever" to occur, or that a past time period seemed to be long. It is less common to hear that a past time period seemed relatively short. It is rare to hear someone say that a future event is approaching more rapidly that expected. In other words, people more often become aware of a duration if various factors influence it in such a way that it seems lengthened, but much less frequently if factors influence it in such a way that it seems shortened (cf. Fraisse, 1963, pp. 201–210). Instances in which a person gives a numerical estimate of a duration show the same sort of psychological influences.

Laboratory experiments typically use one of four major types of duration-judgment methods—production, verbal estimation, reproduction, and comparison (Bindra & Waksberg, 1956). Production and verbal estimation methods use a "translation" of duration into conventional time units (i.e., minutes, seconds, and so on), whereas the latter two methods do not require this translation (although a subject may covertly use such a translation in making a judgment). Apparently because production and verbal estimation methods require such a translation, these methods usually show considerable intersubject variability (Fraisse, 1963).

In the method of production, the experimenter asks the subject operatively to delimit a verbally-stated duration. For example, the subject must press a key at the start and at the end of what he or she judges to be a one-minute period. In the method of verbal estimation, the experimenter operatively delimits a duration, and the subject must estimate it in conventional time units. In the method of reproduction, the experimenter first operatively delimits a duration, such as in the method of verbal estimation. Then the subject must operatively reproduce it, perhaps in the same sort of way as in the method of production. In this case, however, no verbal coding of time is required. In the method of comparison, the experimenter delimits two durations, and the subject estimates them by using some procedure involving a comparison of the two.

Seemingly opposite results may be obtained by using the method of production as compared with the methods of verbal estimation or reproduction, and confusion is possible unless one uses terminology carefully. For example, a subject might be said to "underestimate" a 60–s duration by producing a 50–s duration or to "overestimate" a 60–s duration by verbally judging it to be 68 s long. However, in both cases, the person's experience of

duration is lengthened relative to clock time. It is for this reason that the terms "underestimation" and "overestimation" are meaningless unless they are used in the context of a specific judgment method. To avoid any confusion, I usually prefer to speak of duration experience as being lengthened or shortened.

When this distinction is made, duration experience is occasionally found to depend on the particular judgment method used, which may also interact with other contextual factors (see section 9). Because experiments on the psychology of time have tended to use various kinds of duration-judgment methods more often than other kinds of temporal-judgment methods (e.g., successiveness, spacing, order), the remainder of this chapter mainly focuses on processes involved in duration judgment.

4. CHARACTERISTICS OF THE TIME PERIOD

4.1 Duration of the Time Period

If an event persists for a very brief time, such as for only a few milliseconds, people do not experience duration per se—the event seems instantaneous. However, people can experience and judge duration in a fairly veridical way if an event lasts more than a few hundred milliseconds. That is, as duration increases, judgments follow an approximately linear relationship in the range from about one-half second to a few minutes, as well as in the range from a few hours to a few days (see Block, 1979; Michon, 1975).

Relatively few experiments have studied the range from a few minutes to a few hours. However, the results of a recent study by Aschoff (1985; see also Aschoff, 1984) suggest that "long and short time estimates are based on different mechanisms" (p. 41). Aschoff's subjects lived in isolation, with no external time cues, for periods of 7 days to more than a month. Each of 30 subjects gave two kinds of duration judgment. One kind, a long-duration estimate, required the subject repeatedly to produce 1–hr durations (by signaling every subjective hour, as long as the subject was awake). These productions were, on the average, longer than an hour. The mean production of each subject was positively correlated with the subject's duration of wakefulness as well as with the length of his or her circadian (i.e., sleep-wake) cycle. The other kind, a short-duration judgment, was experimenter-initiated: The experimenter asked the subject to press a button in order to produce a verbally stated duration, which could range from

10 to 120 s. Although there was considerable individual variation, the average production tended to be 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) These judgments were not correlated with the 1–hr productions. In contrast to those long-duration judgments, these short productions were not correlated with either the duration of wakefulness or the length of the sleep-wake cycle.

The conclusion that the processes involved in making short-duration (10–120 s) judgments differ from those involved in making long-duration (1 hr) judgments should be regarded as tentative. It could be that the short productions differed qualitatively from the long productions because of the difference in methods used to obtain them. As Aschoff noted, his findings need to be replicated in an experiment that uses the same method to assess both short and long duration experiences.

4.2 Affordances and Changes

Since its inception, the experimental study of time has been widely referred to as that of the "perception of time". But in an important (yet widely ignored) paper, Gibson (1975) claimed 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). It is relatively easy for us to agree with Gibson that the perception of space is based, at least in part, on the processes by which an observer picks up information about environmental surfaces, such as that involving texture gradients. Alternatively, it seems that each observer is, as a result of biological evolution and individual learning, "at any given moment, tuned to resonate to the incoming patterns that correspond to the invariants that are significant for it" (Shepard, 1984, p. 433). But what are the ecologically significant incoming patterns, or invariants—what Gibson called *affordances*—to which an observer tunes when he or she experiences time, rather than space? According to Gibson (1975), "a sequence of external stimuli or, at the very least, the rhythms of the observer's body, provide a flow of *change*, and it is this we perceive rather than a flow of time as such" (p. 299). Gibson also emphasized that "the observer perceives *both what is altered and what remains unaltered in the environment*" (p. 298). I contend that what is altered or changed is most critical for temporal experiences. Along related lines of thinking, the physicist Mach (1883/1942) observed:

We must not forget that all things in the world are connected with

> one another and depend on one another, and that we ourselves and all our thoughts are also a part of nature. It is utterly beyond our power to *measure* the changes of things by *time.* Quite the contrary, time is an abstraction, at which we arrive by means of the changes of things ... (p. 273).

An ancient Chinese document, *The I Ching, or Book of Changes,* made perhaps the first distinction between different kinds of change (see Block, in press). To "translate" the distinction made in the *Book of Changes* into more contemporary language, nonchange is what remains unaltered in the environment. It is the automatically processed background upon which all cognition of change occurs. The *Book of Changes* also discussed two kinds of change, cyclic and successive. Cyclic changes are events that recur on a periodic basis; an organism's cognitive system usually processes these events in a relatively automatic (i.e, nonconscious) way. Successive changes are relatively unique, nonrecurrent events which the cognitive system typically processes in a relatively controlled (i.e., conscious) way, depending on familiarity with the event, the focus of attention, and many other factors.

An ecological description illustrates the ways in which cyclic and successive changes are superimposed on a background of relative nonchange. The typical external environment of a person is fairly stable, or nonchanging, from one moment to the next. Most of the objects in a room—walls, desks, carpeting, and so on—remain largely unaltered for relatively long periods. Against this background of stability, some changes occur: a telephone rings, a bird flies by the window, a neighbor interrupts with a request. These changes, or events, take place in an ordered sequence.

Modern physicists, who have very little need for noetic conceptions of time, acknowledge the possibility of a local ordering of events—event *a* may be said to precede event *b*, at least from one particular spatial frame of reference. As one wry definition says, "Time is nature's way of keeping everything from happening at once" (source unknown). This inevitable ordering of events seems to be a fundamental property of the universe, even one in which no sentient beings speculate about time. This successive ordering also affords us a major source for our common geometrical representation of time's passage, that of a straight line. The fundamental psychological basis for the detection of order relationships is the person's cognitive system. At the time that a person perceives a present event, he or she may remember an event that precedes it and may anticipate an event that might follow it. It is the relatively simultaneous and automatic operation of the totality of remembering-perceiving-anticipating processes that give us an awareness of the fundamental ordering of events.

Another basic temporal affordance concerns relationships between intervals. According to Allen and Kautz (1985), thirteen primitive relationships form the basis for all knowledge about the relationship between any two or more events. These relations are *equals, before/after, meets/met by, overlaps/overlapped by, starts/started by, during/contains,* and *finishes/finished by.* For example, if we say that event X overlapped event Y, then we are asserting that: (a) The interval in which X occurred began before the interval in which Y occurred; (b) The interval in which Y occurred began before the conclusion of event X; and (c) The interval in which Y occurred ended after the conclusion of event X. Information about some of these relationships, such as before/after, may by picked up and stored in memory as a by-product of the apparently automatic encoding of contextual information along with the memory representation of an event (cf. Hintzman & Block, 1971, 1973; Hintzman et al., 1973, 1975). The cognitive system probably does not automatically encode all of these relationships, however, and a person frequently must draw inferences about relationships among events. Consider, for example, the temporal ambiguities in the sentence: "Before the dinner party began, John felt apprehensive, but Mary's comment relaxed him". In the context of this chapter, two important concepts of Allen and Kautz's theory are that "our perception of time is intimately connected (or identical to) our perception of events" and that "time (or events) appears to be hierarchically organized" (p. 253).

Allen and Kautz (1985) also discussed "a logic for reasoning about durations, which is separate from, but integrates nicely with, the basic interval logic" (p. 259). From a psychological—rather than a purely logical—viewpoint, I previously argued that if one considers a cohesive sequence of events, distinctive events mark the beginning and end of the interval. Most importantly, a distinctive cognitive context persists throughout such a time period, and it is "what unifies long durations, so that even long time periods can be properly called durations" (Block, 1979, p. 187).

In addition to relatively unpredictable events, there are other, somewhat more predictable ones, changes that are cyclic. Rhythms of light and darkness, relative cold and warmth, regular activities such as work schedules, and other cyclic events form a somewhat more slowly changing background to our lives than the more abrupt, transient, successive changes. The cyclic changes which we experience also include internal, biological rhythms—heart beats, wakefulness and sleep, hunger, and so on. Even if there are few or no external changes—such as when a person is in a condition of isolation—internal rhythms may be salient enough to enable the person to construct a near-veridical frame of reference in time.

Campbell (1986) studied the "estimation of empty time" by subjects

who spent 60 hr confined to bed in an isolation unit affording only minimal temporal cues. He prohibited them from engaging in activities like reading, exercise, listening to music, and so on. At various relatively long intervals (ranging from 5.2 to 23.5 hr) during the isolation period, he asked them to estimate the time of day. Campbell found that subjects verbally underestimated the intervals—"the mean subjective hour [continued] for 1.12 h in real time" (p. 205). However, as Campbell noted, Lavie and Webb (1975) had found that subjects verbally underestimate long intervals by about the same amount in experiments in which they are not strictly isolated—that is, those in which subjects may fill the time period by engaging in various kinds of activity.

What cues might a person use to judge duration in an isolated environment? For that matter, what cues might a person use to judge duration in a more normal environment? In a discussion of memory, Bower (1972) mentioned several different kinds of internal contextual elements: interoceptive stimulation (such as posture, temperature, nausea, boredom) and the "psychological context"—"what the subject is thinking about", or "the internal monologue" (p. 93). Over longer periods, a person might remember the number of sleep epochs, menstrual cycles, and so on.

Hewitt (1979) distinguished between two kinds of contextual elements. There are some characteristics of a stimulus that a person must encode in order to perform a task. Hewitt called these the *intrinsic context.* There are also background attributes or features that a subject need not necessarily encode. Hewitt called these the *extrinsic context.* In this regard, Hewitt adopted the traditional, narrow view that context is a property of the external environment. Baddeley (1982) thought that Hewitt's distinction was too passive and stimulus-determined; he preferred to emphasize the processing in which the person engages rather than the characteristics of the stimulus material. As an alternative, then, Baddeley distinguished between what he called *interactive context* and what he called *independent context.* Contextual information is interactive if it "determines the way an item [i.e., some focal information] is encoded" (Baddeley, 1982, p. 710). On the other hand, if a person may encode contextual information and focal information separately, the contextual cue is independent.

Hewitt's and Baddeley's distinctions are both useful, although they differ only slightly in emphasis. It is important to remember that context is always an internal, cognitive construction, just as time is a construction based on change. This implies a recognition of a broader meaning of the term *context*, in which it refers to cognitive structures, or knowledge, supplied by a person as he or she interacts with the environment. Although Baddeley's shift in emphasis is a step in this direction, both the background

characteristics of a person and individual differences in activities or strategies of information processing receive too little emphasis in Hewitt's and Baddeley's accounts.

4.3 Number of Events

Several studies have found that the number of events which occur during a time period influences duration judgment. The nature of the influence, however, depends on whether the judgments are made prospectively or retrospectively (see section 5.3), and it may also depend on the duration of the time period (see Poynter & Homa, 1983).

Under prospective conditions, subjects experience a brief (e.g., a few seconds or less) duration that is filled by external events, such as a series of tones, as being longer than an equal duration that is "empty", or unfilled by external events (e.g., Thomas & Brown, 1974). Subjects also experience a brief stimulus that contains a greater number of elements as being longer in duration than one that contains fewer elements (Mo, 1971). For longer durations, however, such as those measured in minutes, hours, or days, a commonly reported experience is that time seems to pass more quickly if more events are occurring. When there is less than the desired amount of contextual change, such as when one is waiting for a steady Pacific Northwest U. S. drizzle to end, time in passing may seem endless (see section 9).

Under retrospective conditions, though, a person may use an availability heuristic to reconstruct the duration: To the extent that a greater number of events is available in memory, a person remembers the duration of a time period as being longer (Ornstein, 1969; Vroon, 1970). However, it is clear that people do not base this judgment on the degree of recallability of events from the time period (Block, 1974). Other processes, such a person's implicit assessment the amount of contextual change during the duration, appear to be involved (see sections 4.4 and 6.3).

4.4 Complexity of Events and Sequences of Events

In one of Ornstein's (1969) experiments, subjects viewed a single geometric figure during a 30s time period. Ornstein found that the remembered duration of the time period lengthened if subjects had viewed a more complex figure, although increased figural complexity only influenced duration judgments up to a limit. Two subsequent experiments on

complexity clarify the way in which it influences such retrospective judgments of duration (Block, 1978). The first experiment reveals that if a duration contains a sequence of events, the average complexity of each event does not necessarily influence remembered duration. This finding seems to contradict that of Ornstein. However, the second experiment shows that subjects remember a more complex sequence of events as being longer in duration than a less complex sequence. In Ornstein's study on complexity, the sequence of interpretations of a stimulus is probably more complex if the person is viewing a complex figure than if the person is viewing a simple figure. Thus, the amount of contextual change during a sequence of mental events is apparently the critical factor, not the inherent complexity of the individual stimuli per se.

In another experiment, Ornstein (1969) also found that information provided after an information-processing task may influence the remembered duration of the task. Subjects studied a line drawing for 60 s. Then the experimenter gave some of them a simple interpretation of the drawing. These subjects remembered the duration of the time period as being relatively shorter than did subjects who had received no such simple interpretation. Ornstein explained this finding in terms of the organization of memory. An alternative explanation is that subjects who received the simple interpretation did not retrieve all of their previous interpretations of the figure (i.e., contextual changes) at the time they made the duration judgment.

This latter explanation is also consistent with Poynter and Homa's (1983) finding that if there is less "regularity" of events during a time period, subjects experience the duration of the time period as being longer. There is, in other words, a rough equivalence between the complexity of a sequence, the degree of segmentation of events in a sequence, and changes in cognitive context. If high-priority events periodically segment other events, the high-priority events apparently serve as marker events, or subjective referents of time's passage, and a person remembers a segmented duration as being longer than an unsegmented one (Poynter, 1983).

Predebon (1984) also investigated the complexity of coding of information. He studied how the ability to organize and interpret a prose passage might influence remembered duration. Some subjects received thematic information before the passage, while others received no thematic information. This manipulation influenced memory for the information in the passage in the expected way: Subjects who received thematic information before the passage recalled and comprehended more of it than did the control subjects. However, the manipulation did not influence the remembered duration of the passage. Predebon interpreted his findings in terms of a contextual-change hypothesis on remembered duration (Block, 1978, 1979). Remembered duration is apparently not based on the size of the storage space occupied by memories of stimulus events per se, as Ornstein (1969) suggested, but rather on the overall amount of change in cognitive context during the time period (see sections 6.3 and 7).

5. CHARACTERISTICS OF THE EXPERIENCER

5.1 Biological Rhythms

Endogenous biological rhythms apparently control some time-related behaviors, such as those involved in circadian cycles of activity level (see, for example, Groos & Daan, 1985). Chronobiological research on species such as ground squirrels and honeybees reveals that these biological rhythms, which are genetically programmed characteristics of a species, control behavioral rhythms. Neural pacemakers, such as that located in the suprachiasmatic nucleus of some species, apparently underlie the biological rhythms. Under certain conditions, events during a time period—zeitgebers such as the onset of bright light and other exogenous factors—may entrain, synchronize, and reset these brain mechanisms.

Chronobiologcal models attempt to explain many diverse cyclical behaviors by seeking the physiological basis of a single mechanism, a master pacemaker in the brain of the organism. These models relegate external events to only a minor role, largely because chronobiologists have discovered that many cyclical behaviors continue on an approximately 24-hr (i.e., circadian) cycle even if an organism is isolated from all exogenous changes (see, for example, Aschoff, 1984). This chronobiological account seems necessary, as well as relatively sufficient, to explain the regulation of cyclical behaviors. If it also emphasized influences of various strategies of the organism—such as a person strategically choosing when to sleep and when not to sleep following time-zone shifts that result in "jet lag" experiences—the account might become completely sufficient as an explanation for circadian periodicities in behavior. It might be fruitful to investigate potential interactions between different contextual factors even if the account considers only a single category of time-related behavior, cyclical activity.

In the early part of this century, various "internal clock" theories were popular. One example is Hoagland's (1933) attempt to explain all duration experiences solely in terms of biochemical processes in the brain. Early

theorists like Hoagland extended a biological model beyond its rather limited domain of explanation. Further, he and others ignored the role of activities of the individual. It is now apparent that many temporal experiences and behaviors involve much more than the relatively simple processes proposed in these models.

5.2 History of Reinforcement and "The Internal Clock"

Behavioral psychologists typically study how the contents of short time periods (those measured in seconds and minutes) influence overt responding. Their research on schedules of reinforcement, usually studying animals such as pigeons and rats, shows that animals are sensitive to different interval schedules. On these schedules, the presentation of a reinforcer such as food is contingent upon the organism emitting a specific response, but only after a certain interval has elapsed.

Behavioral psychologists have studied interval schedules in order to try to answer a basic question: In addition to timing durations by relying on intrinsic changes in external stimuli, can animals also use an event-independent timer, or internal clock? The answer is apparently *yes.* One model (see, for example, Church, 1984; Roitblat, 1987) postulates an internal clock which consists of a pacemaker, a switch, and an accumulator. The pacemaker generates pulses at more or less regularly spaced intervals. This implies that there is a linear relationship between subjective duration and actual duration. Experiments, in fact, reliably find such a relationship. At the start of an external timing signal, the switch engages, and pulses begin to be counted in the accumulator. The switch is needed in order to handle the finding that changes in stimuli (e.g., an interrupted timing signal) may stop the clock (i.e., the accumulation of pulses from the pacemaker). In this regard, the internal clock functions like a stopwatch. A working memory briefly maintains a total pulse count, and a reference memory records the approximate number of pulses that elapsed prior to some past reinforcement. On interval schedules, responding increases in probability as a comparison (by a comparator mechanism) of working memory and reference memory shows a similar number of pulse counts.

The proposed timing system is flexible in the sense that it can time various kinds of signals. However, the general contextualistic model suggests that this behavioral model is limited: It does not consider all of the potentially important contextual aspects, such as other activities of an organism during an interval. For example, organisms may time a duration

by engaging in various progressive or repetitive movements that take an appropriate amount of time (see Pouthas, 1985; Richelle & Lejeune, 1980, pp. 188–189). More fundamentally, it remains to be demonstrated that we can generalize this animal model to studies of human temporal experience and behavior.

5.3 Prospective versus Retrospective Outlook

It is critical to distinguish between prospective and retrospective judgment of duration. Fortunately, the failure to consider this distinction in interpreting experimental findings is much less common than it has been in the past. Although the distinction may be viewed as involving a difference in method, interpretations of findings become clearer if this variable is considered to involve a relatively temporary alteration in temporal outlook, a characteristic of the experiencer.

In a prospective paradigm, the experimenter informs a subject beforehand that the experimenter will subsequently ask the subject to make a duration judgment. Usually each subject makes many such judgments for different time periods. Hicks, Miller, Gaes, and Bierman (1977) called the temporal experience involved under prospective conditions "the experience of time-in-passing" (p. 443). I call it *experienced duration* (Block, 1979). In a retrospective paradigm, on the other hand, a subject receives only general orienting instructions beforehand, and only after the time period does the experimenter reveal that the task involves making a duration judgment. I call this *remembered duration.*

This distinction is closely related to the different methods of duration judgment (see section 3.4). When an experiment uses the method of production, a prospective paradigm must be used: The subject must be informed of the task before he or she produces the required duration. When the methods of verbal estimation or comparison are used, either a prospective or a retrospective paradigm may be used. The method of reproduction is a hybrid: The subject may or may not be informed before the duration that is to be reproduced, but the actual reproduction must be made prospectively.

Several theorists have noted that prospective and retrospective paradigms may produce different, even opposite, sorts of duration experiences. James (1890) proposed that experienced duration lengthens when "we grow attentive to the passage of time itself" (p. 626), whereas remembered duration lengthens as a function of "the multitudinousness of the memories which the time affords" (p. 624). Fraisse (1963) suggested that "direct time

judgments [are] founded immediately on the changes we experience and later on the changes we remember" (p. 234). In more recent literature, internal-clock or interval-timer models, which usually focus on experienced duration and ignore the role of controlled strategies of information processing, differ considerably from cognitive-process models, which often focus on remembered duration and emphasize controlled strategies.

The usual conclusion is that a prospective outlook lengthens experienced duration, presumably because a person is "attending to the passage of time itself" (for reviews, see Block, 1979; Hicks et al., 1977). S.W. Brown (1985) found that prospective judgments (verbal estimates and reproductions) tend to be somewhat longer and more accurate than retrospective judgments. He did not find any interaction of paradigm (i.e., prospective vs. retrospective outlook) and "nontemporal task demands" (i.e., difficulty of the information-processing task). However, some researchers (e.g., Hicks, Miller, & Kinsbourne, 1976) have reported interactions of paradigm and other factors, such as the amount of information processed. Such interactions are common, and I describe research revealing interactions between paradigm and other contextual factors later (see sections 7.2 and 9).

5.4 Previous Experience and Changes in Environmental Context

Block (1982) conducted three experiments investigating environmental context as a potential source of contextual changes. In the first two of them, subjects processed the same number of words in the same way during each of two durations. Thus, both the number of events and the complexity of coding of the events were constant. The experiments manipulated the environmental context (i.e., the room, the experimenter, the form of the materials, and so on) in which the two durations occurred. For some other subjects, the environmental context was both disrupted and changed between the two durations—that is, they experienced the second time period in an environment which was different from that in which they spent the first time period. These subjects remembered the duration of the second time period as being relatively longer than did subjects in a control condition in which the environmental context had been neither disrupted nor changed. For some other subjects, the environmental context was simply disrupted between the two durations—that is, subjects left and then returned to the same room in between the two time periods. These subjects remembered the duration of the second time period as being slightly longer than did subjects in the control condition. Thus, to the extent that

the encoding of the environmental context during the second time period was changed in some way, subjects remembered the duration of the second time period as being relatively longer. These experiments reveal clearly that characteristics of the experiencer—specifically, the person's previous experiences in a particular environment—influence remembered duration.

5.5 Previous Experience and the Time-Order Effect

Research on remembered duration also reveals another major finding: With all other factors equal or controlled by counter-balancing, subjects remember the first of two equally long time periods as being longer in duration than the second time period. This so-called *positive time-order effect* is so robust and ubiquitous that it plays an important theoretical role in the present contextualistic view, as well as in exploring influences of different contextual factors. A theoretically important question concerns whether or not the effect can be eliminated. Changing the environmental context that prevails during the second of two durations does, in fact, eliminate it (Block, 1982). It is also eliminated if changes in emotional context that might ordinarily have occurred during the first duration occur instead during a preceding experimental task (Block, 1986). These changes in emotional context are the feelings, moods, and concerns that accompany a new task, such as being a participant in an experiment. Thus, we can attribute the typical finding of a positive time-order effect in remembered duration to the greater contextual changes that ordinarily occur during the first of two durations. The encoded cognitive context apparently changes much more rapidly as a person initially experiences a particular situation than it does later.

6. ACTIVITIES DURING THE TIME PERIOD

6.1 Information-Processing Strategies

Recent cognitive research in general, and cognitive research on time in particular, has tended more and more to emphasize controlled strategies of information processing (see, for example, Michon, in press). The selection and use of particular strategies, such as kinds of attentional deployment

and mnemonic involvement, depend on the ways in which each individual, with a certain past history of learning, interacts with an information-processing task. As I noted earlier, Jackson (1985, 1986; Michon & Jackson, 1984) has obtained considerable evidence that individual differences in controlled strategies influence temporal information processing, such as that which provides the basis for judgment of temporal order or serial position.

Other evidence that a person's information-processing activities might be important comes from Underwood's studies of remembered duration (G. Underwood, 1975; Underwood & Swain, 1973). Underwood and Swain found that subjects remembered a prose passage which required greater selectivity of attention for its analysis as being longer in duration than one which required less attention. Other studies, however, have not found the expected influence of attentional manipulations on remembered duration (S. W. Brown, 1985; Gray, 1982). The ways in which attentional selectivity might influence remembered duration are still unclear, but it seems likely that attentional selectivity interacts with task demands and information-processing strategies. In the present contextualistic model, attentional selectivity, which Underwood regarded to be the principal determinant of duration experience, is merely one of several factors. Like the others, it influences duration experiences through interactions with other factors.

6.2 Levels of Processing

Block and Reed (1978) conducted two experiments that reveal one way in which information-processing strategies influence remembered duration. In their first experiment, subjects processed words at either a shallow, structural level or at a deep, semantic level. Then they performed the other kind of processing during a second time period of equal length. Subjects remembered the duration of the deep-processing task as being about as long as that of the shallow-processing task. (As expected, subjects recognized the words that they had processed in a deep way much more accurately than those that they had only processed in a shallow way.) Level of processing, by itself, apparently has little or no influence on remembered duration.

6.3 Changes in Processing

In a second experiment, Block and Reed (1978) required subjects either to perform structural or semantic processing (as in the first experiment)—unmixed processing—or to alternate between the two kinds of processing—mixed processing. During the first of two durations, some subjects engaged in unmixed processing, whereas others engaged in mixed processing. During the second time period, subjects performed the other kind of task. Subjects remembered the duration during which they performed mixed processing as being longer than the duration during which they performed unmixed processing, regardless of whether the unmixed processing was structural or semantic. Thus, the remembered duration of a time period lengthens if there are changes in the kinds of activities, or strategies, that a person uses to encode events occurring during the time period.

Based on these findings, Block and Reed (1978; see also Block, 1979) proposed that remembered duration involves an implicit assessment of memory for the overall change in cognitive context during a time period. In their experiments, variations in what they called *process context*—the context accompanying the performance of different kinds of tasks—apparently produced a major kind of contextual change, a change in certain aspects of the internal context. Because the mixed-processing task required different kinds of cognitive processes, the cognitive context changed. The quality of the mental events that occurred during the time period apparently influenced remembered duration in a fairly direct way. Remembered duration apparently involves a cognitive construction based on this quality, what Block and Reed called the amount of contextual change—rather than one based on memory for stimulus events per se.

7. TWO-FACTOR INTERACTIONS

There are six different two-factor interactions between the four general factors I have discussed. In this section I mention only two of the more widely investigated two-factor interactions.

7.1 Characteristics of the Time Period and Activities during the Time Period

Vroon (1970) conducted two experiments on remembered duration that reveal interactions between the contents of a time period and a person's activities during the time period. In the first one, the task required subjects merely to pay attention to some presented information; across subjects, a different number of tones occurred during the time period. The remembered duration of the time period lengthened if there had been a greater number of tones. Thus, the more numerous were the changes, the longer was the remembered duration of the task. In contrast, Vroon's second experiment required subjects to make one of two overt responses to each tone, depending upon its pitch. In this situation, the subjects remembered the duration of the time period as being shorter if they had processed a greater amount of information; this is the opposite sort of finding from that of the first experiment.

One possible interpretation for these findings is that active processing requires substantial attention, so that for each item which a subject must actively process, correspondingly less attention is available for a subject to encode changes in events occurring during the time period. In other words, subjects who actively make decisions about information encode and remember fewer changes during the time period if there are more decisions that they must make, and as a result they judge the remembered duration as being shorter. The specific cognitive processes involved when a person remembers the amount of information presented or the amount of information processed are not obvious, and neither are the processes involved when a person remembers the overall amount of change during a time period. Future research must attempt to investigate this critical issue.

7.2 Characteristics of the Experiencer and Activities during the Time Period

Several studies have explored possible interactions between characteristics of the experiencer and activities during the time period. Hicks et al. (1976) varied the temporal outlook of subjects by telling half of them that they would later be asked to make a duration judgment (prospective condition); the experimenter did not mention this to the other half of the subjects (retrospective condition). In addition, the experiment varied the amount of information that subjects processed during a time period. Subjects either dealt standard playing cards into a single pile (0–bit condition), sorted them by color (1–bit condition), or sorted them by suit (2–bits condition). Then all subjects verbally estimated the duration of the task. In the prospective condition, the experienced duration of the task was shorter if the subjects had processed more information. This is what we expect if the more difficult tasks competed with the implicit request that subjects attend to temporal cues, such as contextual changes. In the retrospective condition, on the other hand, the remembered duration of the task was not influenced by the amount of information processed, a finding which contrasts with that of Vroon (1970).

Miller, Hicks, and Willette (1978) required subjects to study a 30–word list for a differing number of trials prior to a critical trial. This varied the person's familiarity with the materials, a characteristic of the experiencer. Before the critical trial, the experimenter told half of the subjects that they would later be asked to make a duration judgment (prospective condition) but did not tell the other half about the subsequent judgment (retrospective condition). This varied another characteristic of the experiencer—the person's temporal outlook. On the critical trial—either the first, third, or ninth trial—half the subjects were told to rehearse the words, whereas the other half were told to rest. This varied the person's activity during the time period. Then all subjects verbally estimated the duration of the critical trial. Verbal estimates were greater in the prospective condition than they were in the retrospective condition. Prior experience (i.e., previous trials) did not influence the duration judgment of subjects who did not actively rehearse; there was only a main effect of temporal outlook (prospective vs. retrospective). For subjects who rehearsed, on the other hand, the experienced duration of the time period lengthened as the number of previous study trials increased, whereas the remembered duration of the time period shortened as trials increased.

Thus, just as James (1890) originally claimed, the experience of duration in passing may differ from the experience of duration in retrospect. In Miller et al.'s study, the two kinds of temporal outlook interacted with other contextual factors to influence duration judgment. Miller et al. interpreted their finding that experienced duration lengthened as the number of previous trials increased by referring to decreased information-processing demands. In other words, the rehearsal task was less attention-demanding for subjects who had more experience with the events occurring during the time period, so they were able to allocate more attention to temporal information processing. In the retrospective condition, on the other hand, Miller et al. concluded that "duration judgments are based on memory for the amount of processing done" (p. 178). An alternative in-

terpretation is that contextual changes are greater when a person is encountering relatively novel information, just as in situations which show a positive time-order effect (see section 5.5).

The third experiment in a series that I described earlier (Block, 1982; see section 5.4) also explored possible interacting influences of characteristics of the experiencer and activities during the time period. Specifically, the first variable was whether or not subjects spent the second duration in a room that was different from the one in which they spent the first duration. The other variable was whether subjects engaged in mixed semantic and structural processing or engaged in only a single type of processing (cf., Block & Reed, 1978, Experiment 2, which I discussed in section 6.3). Duration judgments showed a main effect of processing type which replicated that found in the earlier experiment. More importantly, the two kinds of contextual factors interacted: If there had been no change in environmental context between the two durations, there was a substantial influence of type of processing; but if the environmental context had been changed, there was no influence of type of processing. A possible explanation for the interaction is that changes in environmental context were more salient than changes in type of processing. In other words, different kinds of contextual factors may not simply add to lengthen remembered duration. A person's subjective reaction to the quality, or total meaning, of the situation is critically important.

Several other experiments also reveal interactions between characteristics of the experiencer and activities during the time period. Block (1986) conducted four experiments in which subjects saw the same number of words during each of two equal time periods. During each time period, they performed one of two different kinds of imagery tasks involving the words. One task, the environmental-imagery task, required the deliberate encoding of environmental stimuli. Subjects imagined the referent of each presented word interacting with a unique object or location in the experimental room. The other task, the internal-imagery task, restricted the deliberate encoding of environmental stimuli. Subjects imagined the referent of each word either in a single location or interacting in an internal image with the referent of the preceding word. The results in either case were the same: Subjects remembered the internal-imagery task as being longer in duration than the environmental-imagery task. Two additional experiments suggest a possible explanation for the influence of imagery task. Before performing the imagery tasks, subjects wrote either a description of the experimental room, relying on ordinary perceptual processes, or a description of another room, relying on imagery processes. The preceding description condition interacted with the subsequent imagery task: If subjects performed a certain kind of cognitive processing during the preceding description task, they remembered the duration of the imagery task that required a different kind of cognitive processing as being relatively longer.

These findings rule out a contextual explanation in terms of the encoding of varied environmental associations, because subjects remembered the environmental-imagery task as being shorter, rather than longer, than the internal-imagery task. In addition, the findings suggest another kind of contextual explanation: The factor that is critical in determining remembered duration in this situation involves the more holistic changes in context attributable to the type of processing involved in the performance of an imagery task. In other words, an overall change in context from the preceding period to the judged duration, operating during the judged duration, is apparently responsible.

8. THREE-FACTOR INTERACTIONS

The chronobiological and behavioral models which I discussed earlier (see section 5.1 and 5.2) are actually three-factor models, although the emphasis that they place on some of the factors is very minimal (Block, in press). In addition, these models typically do not acknowledge possible complex interactions between factors, only relatively simple cause-and-effect relationships, which are bound to be a misleading oversimplification of the reality of any complex process.

Some cognitive models, such as Ornstein's (1969) storage-size model, are also fundamentally three-factor models. But cognitive models typically discuss how activities during the time period, such as strategies, interact with other contextual factors to influence temporal experiences. However, some of these models also do not include all of the potentially important interactions of factors, and usually the models focus only on one kind of temporal judgment, such as duration judgment. Thus, many cognitive models also tend to be somewhat limited in scope.

9. FOUR-FACTOR INTERACTIONS

To my knowledge, no one has systematically explored the complex, four-factor interactions predicted by the general contextualistic model. However, one set of experiments comes rather close.

My colleagues and I (Block, George, & Reed, 1980) varied all four kinds of factors in a series of experiments on the watched-pot phenomenon (as in the aphorism, "A watched pot never boils"). We asked people to observe a beaker of water on an electric burner. We varied one characteristic of the experiencer by giving some of the observers a prospective outlook: We told them that we would later ask them to judge duration. We gave other observers a retrospective outlook: We told them that the experiment concerned perception, and we included no forewarning about the subsequent duration judgment. We varied changes in the focal contents of the duration by arranging for the water to boil for some of the observers, whereas for the others it did nothing at all. We varied the observers' activities during the duration by distracting some of them with questions unrelated to the task. These three factors interacted, and the nature of the interaction depended on whether the duration-judgment task involved reproduction or verbal estimation of the duration.

By exploring interactions among all four contextual factors, we arrived at a better understanding of the watched-pot phenomenon. Previous theories have focused on variables such as attention to the passage of time, waiting, vigilance, and selectivity of attention. Our study confirms that the degree to which a person is attending to the passage of time is an important factor. We can assume that observers in the prospective condition were highly aware of the duration while it was in progress, and they reproduced it as longer than did those in the retrospective condition. One of the interactions also supports this explanation: If there were no changes in events occurring during the time period (i.e., no boiling), observers in the prospective condition reproduced the duration as longer if they were not distracted than if they were distracted. Thus, "attention to the passage of time" seems to be characteristic of a person adopting a prospective outlook on the ongoing situation.

On the other hand, circumstances which are thought to produce the watched-pot phenomenon did not have the expected influence on reproductions made under retrospective conditions. Observers remembered the duration of the time period as being longer if there were either changes in the contents of the time period (i.e., boiling), changes in the observer's activities (i.e., a distraction), or both. These findings support the contextual-change hypothesis on remembered duration which I described earlier (see section 6.2).

10. DEVELOPMENT OF TEMPORAL EXPERIENCES AND CONCEPTS

A general contextualistic model can also help clarify the processes involved in the development of temporal experiences and concepts. During the earliest stages of human development, a child apparently cannot separate relatively stable objects in space from relatively transient events in time. Presumably, simultaneity and successiveness are more fundamental than other kinds of time-related concepts, such as duration. Some of the processes involved in experiences of simultaneity of two (or more) interacting event sequences probably occur fairly automatically. These processes may provide the basis for subsequent acts of temporal measurement and judgment. In spite of this automaticity of some processes, judgment of simultaneity is actually rather complex, in the sense that several physiological and cognitive factors, such as stimulus modality and attentional focus, influence the underlying processes (for a review, see Block, 1979). Preoperational children tend to make errors in judging velocity and duration which can be traced, in part, to their inability to coordinate the simultaneities of different events (Piaget, 1946).

As remembering and anticipating abilities develop in the young child, so too does the notion of an extended present—the "saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time" (James, 1890, p. 609). The changes from which a child constructs the notion of a present are the interweavings of events occurring in different progressions, or movements—activations of different, yet now related, schemata forming the contents of consciousness. The experiencing of rhythm, such as in music or speech, is apparently also based on such contextual relationships between events forming part of the psychological present.

Fairly young children (as young as age 7, and perhaps younger) can often remember the relative order or recency of two events that occurred in the same strand, or progression of events. From ages 7 through 18, there is also little or no developmental trend in the accuracy of recency judgments (A. L. Brown, 1973). These findings suggest that contextual encoding of events occurs relatively automatically and that under some circumstances the stored contextual information is sufficiently distinct to support some temporal judgments. Yet even adults have difficulty remembering the temporal order of events that did not occur in a natural order, or of unrelated events that were encoded in a similar context (Hintzman & Block, 1973).

During the concrete– and formal-operational periods of development, remembering temporal-order relationships may require particular encod-

ing strategies as well as relatively effortful processes involving the reconstruction of relationships between landmark events—easily remembered activities, seasons of the year, and so on (Friedman & Wilkins, 1985; B. J. Underwood, 1977). A child is then able to form "the notion of different event sequences crisscrossing each other but converging upon the momentary state of the reflecting observer" (Riegel, 1977, p. 8).

The experienced duration of an event or interval between events must necessarily depend on an ability to remember the initial onset of an event, an ability which appears very early in human development (see Pouthas, 1985). However, as other cognitive abilities also develop, many other factors begin to influence experienced duration, such as anticipation. Older children and adults realize that the remembered duration of a time period is a personal reconstruction that may be influenced by a wide variety of contextual factors (see section 11). In addition, a typical concrete-operational child is probably aware that a time period which contains many personally important marker events might seem relatively long, as compared to the experience of another observer, such as a parent.

During the formal-operational period of development, most adolescents are able to form relatively abstract, scientific-like conceptions of time (see section 11). As a result, they are able to view time in a more absolute way, rather than in a way which is entirely relative to their personal experiences. It is then that adolescents attain a broad temporal perspective—a way of relating to past, present, and future events, which may be remembered, experienced, and anticipated. Of course, adults construct a temporal perspective not only from relatively automatic, species-wide temporal experiences, but also from relatively controlled, culturally specific temporal conceptions and beliefs. Consider now adults' temporal conceptions and beliefs.

11. ADULT BELIEFS ABOUT TIME AND TEMPORAL EXPERIENCES

My colleagues and I designed and conducted a reasonably comprehensive survey of beliefs about time and temporal experiences (Block, Saggau, & Nickol, 1983–84). The respondents were college students in the U.S. Subsequently, we surveyed college students in Japan and Malawi as well (Block, Buggie, & Saggau, 1987). We asked all of them to respond to a questionnaire—the Temporal Inventory on Meaning and Experience (TIME)—concerning physical time, personal time, experienced duration,

and remembered duration. For example, in a part on experienced duration the respondents indicated whether a time period that a person is experiencing seems to pass more quickly or more slowly if the person is performing a pleasant versus an unpleasant activity, or a single kind of task versus several kinds of tasks. In a similar part of the TIME concerning remembered duration, respondents rated whether the same kinds of factors would make a time period that a person is remembering seem shorter or longer.

What is especially striking about these data is that the respondents' beliefs about experienced and remembered duration were remarkably similar. Regardless of the country, the respondents reported that many different kinds of factors influence the experiencing and remembering of duration.

It seems that people are "naive contextualists": They agree that a wide variety of factors influence the quality of human temporal experiences. Perhaps people from around the world develop these similar beliefs as a result of experiencing certain common phenomena of psychological time. This personal awareness of various contextual influences on duration experiences is apparently somewhat limited, however. When we asked how various factors, such as feeling strong emotions, influence how quickly or slowly time seems to pass, respondents' beliefs usually were in accord with evidence obtained in studies using prospective duration judgments. But when we asked how the same factors might influence whether a person remembers a time period as being relatively short or long, the reported beliefs often conflicted with evidence obtained in studies using retrospective duration judgments. In general, reported beliefs did not reflect the typical conclusion that a time period which seems to pass quickly (for whatever reason) might later be remembered as being relatively long, rather than relatively short. The naive contextualism displayed by the respondents is not necessarily the same as the scientific contextualism revealed by empirical studies of duration judgment.

Responses to statements concerning physical time are also of interest. On these, reported beliefs varied considerably from one country to the next. For example, Japanese respondents agreed more frequently than American or Malawian respondents that time is cyclical. Japanese respondents also agreed more frequently with statements expressing a relativistic, Einsteinian view of physical time, as opposed to an absolute, Newtonian view. These relatively large differences in beliefs concerning more abstract, scientific-like views on physical time may occur because people do not have any first-hand experiences relevant to scientific conceptions of time. Education and scientific training might be heavily involved in the formation of beliefs about physical time.

12. CONCLUSIONS

A general contextualistic model is a useful heuristic for viewing the results of experiments. It forces us to consider and to appreciate the complex interactions of contextual factors involved when people construct and represent time. In addition to this heuristic value, a contextualistic model facilitates the interpretation of recent findings. Many experiments on the psychology of time (only a few of which I have mentioned in this chapter) reveal how interactions among four major kinds of contextual factors influence psychological time. A contextualistic framework can easily accommodate other kinds of evidence, such as from reported beliefs of nonscientists about temporal experiences.

We need to continually question the models we implicitly or explicitly adopt. Given our present understanding of the psychology of time, though, a contextualistic model has been and will continue to be a fruitful one.

References

Allen, J. F., & Kautz, H. A. (1985). A model of naive temporal reasoning. In J. R. Hobbs & R. C. Moore (Eds.), *Formal theories of the commonsense world* (pp. 251–268). Norwood, NJ: Ablex.

Aschoff, J. (1984). Circadian timing. In J. Gibbon & L. Allan (Eds.), *Timing and time perception* (pp. 442–468). New York: New York Academy of Sciences.

Aschoff, J. (1985). On the perception of time during prolonged temporal isolation. *Human Neurobiology, 4*, 41–52.

Baddeley, A. D. (1982). Domains of recollection. *Psychological Review, 89*, 708–729.

Bindra, D., & Waksberg, H. (1956). Methods and terminology in studies of time estimation. *Psychological Bulletin, 53*, 55–59.

Block, R. A. (1974). Memory and the experience of duration in retrospect. *Memory & Cognition, 2*, 153–160.

Block, R. A. (1978). Remembered duration: Effects of event and sequence complexity. *Memory & Cognition, 6*, 320–326.

Block, R. A. (1979). Time and consciousness. In G. Underwood & R. Stevens (Eds.), *Aspects of consciousness: Vol. 1. Psychological issues* (pp. 179–217). London: Academic Press.

Block, R. A. (1982). Temporal judgments and contextual change. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 530–544.

Block, R. A. (1985a). Contextual coding in memory: Studies of remembered duration. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 169–178). Berlin: Springer-Verlag.

Block, R. A. (1985b). World models for the psychology of time. *Teorie & Modelli, 2* (Suppl. 1), 89–111.

Block, R. A. (1986). Remembered duration: Imagery processes and contextual encoding. *Acta Psychologica, 62*, 103–122.

Block, R. A. (in press). A contextualistic view of time and mind. In J. T. Fraser (Ed.), *Time and mind: The study of time VI*. Madison, CT: International Universities Press.

Block, R. A., Buggie, S. E., & Saggau, J. L. (1987). *Beliefs about time in Japan, Malawi, and the United States.* Manuscript in preparation.

Block, R. A., George, E. J., & Reed, M. A. (1980). A watched pot sometimes boils: A study of duration experience. *Acta Psychologica, 46*, 81–94.

Block, R. A., & Reed, M. A. (1978). Remembered duration: Evidence for a contextual-change hypothesis. *Journal of Experimental Psychology: Human Learning and Memory, 4*, 656–665.

Block, R. A., Saggau, J. L., & Nickol, L. H. (1983–84). Temporal Inventory on Meaning and Experience: A structure of time. *Imagination, Cognition and Personality, 3*, 203–225.

Bower, G. H. (1972). Stimulus-sampling theory of encoding variability. In A. W. Melton & E. Martin (Eds.), *Coding processes in human memory* (pp. 85–123). Washington, DC: Winston.

Bransford, J. D. (1979). *Human cognition: Learning, understanding, and remembering.* Belmont, CA: Wadsworth.

Brown, A. L. (1973). Judgment of recency for long sequences of pictures: The absence of a developmental trend. *Journal of Experimental Child Psychology, 15*, 473–480.

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception & Psychophysics, 38*, 115–124.

Campbell, S. S. (1986). Estimation of empty time. *Human Neurobiology, 5*, 205–207.

Church, R. M. (1984). Properties of the internal clock. In J. Gibbon & L. Allan (Eds.), *Timing and time perception* (pp. 566–582). New York: New York Academy of Sciences.

Fraisse, P. (1963). *The psychology of time.* New York: Harper & Row.

Friedman, W. J., & Wilkins, A. J. (1985). Scale effects in memory for time of events. *Memory & Cognition, 13*, 168–175.

Gibson, J. J. (1975). Events are perceivable but time is not. In J. T. Fraser & N. Lawrence (Eds.), *The study of time II* (pp. 295–301). New York: Springer-Verlag.

Gray, C. (1982). Duration differences: Attentional demand or time error? *Perception, 11*. 97–102.

Groos, G., & Daan, S. (1985). The use of biological clocks in time perception. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 65–74). Berlin: Springer-Verlag.

Hewitt, K. (1979). *Contextual aspects of memory in normal and pathological states.* Unpublished master's thesis, Cambridge University.

Hicks, R. E., Miller, G. W., Gaes, G., & Bierman, K. (1977). Concurrent processing demands and the experience of time-in-passing. *American Journal of Psychology, 90*, 431–446.

Hicks, R. E., Miller, G. W., & Kinsbourne, M. (1976). Prospective and retrospective judgments of time as a function of amount of information processed. *American Journal of Psychology, 89*, 719–730.

Hintzman, D. L., & Block, R. A. (1971). Repetition and memory: Evidence for a multiple-trace hypothesis. *Journal of Experimental Psychology, 88*, 297–306.

Hintzman, D. L., & Block, R. A. (1973). Memory for the spacing of repetitions. *Journal of Experimental Psychology, 99*, 70–74.

Hintzman, D. L., Block, R. A., & Summers, J. J. (1973). Contextual associations and memory for serial position. *Journal of Experimental Psychology, 97*, 220–229.

Hintzman, D. L., Summers, J. J., & Block, R. A. (1975). Spacing judgments as an index of study-phase retrieval. *Journal of Experimental Psychology: Human Learning and Memory, 105*, 31–40.

Hirsh, I. J. (1959). Auditory perception of temporal order. *Journal of the Acoustical Society of America, 31*, 759–767.

Hirsh, I. J. & Sherrick, C. E., Jr. (1961). Perceived order in different sense modalities. *Journal of Experimental Psychology, 62,* 423–432.

Hoagland, H. (1933). The physiologic control of judgments of duration: Evidence for a chemical clock. *Journal of General Psychology, 9,* 267–287.

Jackson, J. L. (1985). Is the processing of temporal information automatic or controlled? In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 179–190). Berlin: Springer-Verlag.

Jackson, J. L. (1986). *The processing of temporal information.* Doctoral dissertation, Rijksuniversiteit te Groningen.

Jackson, J. L., & Michon, J. A. (1984). Effect of item concreteness on temporal coding. *Acta Psychologica, 57,* 83–95.

James, W. (1890). *The principles of psychology, Vol. 1.* New York: Henry Holt.

Jenkins, J. J. (1979). Four points to remember: A tetrahedral model of memory experiments. In L. S. Cermak & F. I. M. Craik (Eds.), *Levels of processing and human memory* (pp. 429–446). Hillsdale, NJ: Erlbaum.

Lavie, P., & Webb, W. B. (1975). Time estimates in a long-term time-free environment. *American Journal of Psychology, 88,* 177–186.

Mach, E. (1942). *The science of mechanics* (5th ed., T. J. McCormack, Trans.). LaSalle, IL: Open Court. (Original work published 1883.)

Michon, J. A. (1975). Time experience and memory processes. In J. T. Fraser & N. Lawrence (Eds.), *The study of time II* (pp. 302–313). New York: Springer-Verlag.

Michon, J. A. (in press). Timing your mind and minding your time. In J. T. Fraser (Ed.), *Time and mind: The study of time VI.* Madison, CT: International Universities Press.

Michon, J. A., & Jackson, J. L. (1984). Attentional effort and cognitive strategies in the processing of temporal information. *Annals of the New York Academy of Sciences, 423,* 298–321.

Miller, G. W., Hicks, R. E., & Willette, M. (1978). Effects of concurrent verbal rehearsal and temporal set upon judgments of temporal duration. *Acta Psychologica, 42,* 173–179.

Mo, S. S. (1971). Judgment of temporal duration as a function of numerosity. *Psychonomic Science, 24,* 71–72.

Ornstein, R. E. (1969). *On the experience of time.* Harmondsworth, England: Penguin.

Piaget, J. (1946). *Le developpement de la notion de temps chez l'enfant.* Paris: Presses Universitaires de France.

Pouthas, V. (1985). Timing behavior in young children: A developmental approach to conditioned spaced responding. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind and behavior* (pp. 100–109). Berlin: Springer-Verlag.

Poynter, W. D. (1983). Duration judgment and the segmentation of experience. *Memory & Cognition, 11,* 77–82.

Poynter, W. D., & Homa, D. (1983). Duration judgment and the experience of change. *Perception & Psychophysics, 33,* 548–560.

Predebon, J. (1984). Organization of stimulus events and remembered apparent duration. *Australian Journal of Psychology, 36,* 161–169.

Richelle, M., & Lejeune, H. (1980). *Time in animal behavior.* Oxford: Pergamon.

Riegel, K. F. (1977). The dialectics of time. In N. Datan & H. W. Reese (Eds.), *Life-span developmental psychology: Dialectical perspectives on experimental research* (pp. 3–45). New York: Academic Press.

Roitblat, H. L. (1987). *Introduction to comparative cognition.* New York: Freeman.

Shepard, R. N. (1984). Ecological constraints on internal representation: Resonant kinematics of perceiving, imagining, thinking, and dreaming. *Psychological Review, 91,* 417–447.

Thomas, E. A. C., & Brown, I., Jr. (1974). Time perception and the filled-duration illusion. *Perception & Psychophysics, 16,* 449–458.

Underwood, B. J. (1977). *Temporal codes for memories: Issues and problems.* Hillsdale, NJ: Erlbaum.

Underwood, G. (1975). Attention and the perception of duration during encoding and retrieval. *Perception, 4,* 291–296.

Underwood, G., & Swain, R. A. (1973). Selectivity of attention and the perception of duration. *Perception, 2,* 101–105.

Vroon, P. A. (1970). Effects of presented and processed information on duration experience. *Acta Psychologica, 34,* 115–121.