

HEDE HELFRICH (ED.)

Time and Mind II

Information Processing Perspectives



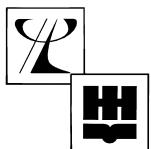
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Time and Mind II:
Information Processing Perspectives

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Time and Mind II: Information Processing Perspectives

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Table of contents

List of contributors	vii
Preface	xii
<i>Part I: Time as an object of information processing</i>	1
<hr/>	
Chapter 1: Simultaneous temporal processing	
RUSSELL M. CHURCH, PAULO GUILHARDI, RICHARD KEEN, MIKA MACINNIS, and KIMBERLY KIRKPATRICK	3
Chapter 2: Applying the scalar timing model to human time psychology: Progress and challenges	
JOHN H. WEARDEN	21
Chapter 3: Psychological timing without a timer: The roles of attention and memory	
RICHARD A. BLOCK	41
Chapter 4: Sensory modalities and temporal processing	
SIMON GRONDIN	61
Chapter 5: Notable results regarding temporal memory and modality	
FLORIAN KLAPPROTH	79
Chapter 6: Sensory and cognitive mechanisms in temporal processing elucidated by a model system approach	
THOMAS RAMMSAYER	97

<i>Part II: Time as a constituent of information processing</i>	115
Chapter 7: Temporal characteristics of auditory event-synthesis: Electrophysiological studies ISTVÁN CZIGLER, ISTVÁN WINKLER, ELYSE SUSSMANN, HIROOKI YABE, and JÁNOS HORVÁT	117
Chapter 8: Exploring the timing of human visual processing SIMO VANNI, MICHEL DOJAT, JAN WARNKING, CHRISTOPH SEGEBARTH, and JEAN BULLIER	125
Chapter 9: Time and conscious visual processing ANDREAS K. ENGEL	141
Chapter 10: Hypothesized temporal and spatial code properties for a moment's working memory capacity: Brain wave "harmonies" and "four-color" topology of activated cortical areas ROBERT B. GLASSMAN	161
Chapter 11: Invariants of mental timing: From taxonomic relations to task-related modeling HANS-GEORG GEISSLER and RAUL KOMPASS	185
Chapter 12: Behavioral and electrophysiological oscillations in information processing: A tentative synthesis BORÍS BURLE, FRANÇOISE MACAR, and MICHEL BONNET	209
Subject Index	233
Author Index	239

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Preface

This book focuses on the significance of time in information processing and thus broadens the perspective of the first *Time and Mind* volume (Helfrich, 1996).^{*} Two areas of research are distinguished. The first deals with time estimation and the temporal coordination abilities of humans and animals. The second area of research deals with the role of temporal properties in processes involving perception and memory. Thus, the following two main topics constitute the structure of the book: “time as an object of information processing” and “time as a constituent factor in information processing.” The aim of the book is to investigate both topics and to show possible ways to integrate the two research fields.

The book is based on the symposium “Time and Mind 02” held at the University of Hildesheim from September 2nd–4th, 2002. The Deutsche Forschungsgemeinschaft (DFG), the Universitätsstiftung, and the University of Hildesheim supported the idea of the symposium and provided grants to organize it.

Part I: Time as an object of information processing

First of all, animals and humans have no sense organ specialized to perceive time. Nevertheless, we speak of “time perception” and do not rule out the possibility that perceptual systems are tuned to temporal information. The processing of temporal information shares some important characteristics with the processing of visual, auditory, and other perceptual information. The theoretical model mainly discussed in this context is that of an *internal clock*. The contributions by RUSSELL CHURCH and colleagues as well as by JOHN WEARDEN focus on how an internal clock may operate as a kind of proximal or inner stimulus in both humans and animals. Although the metaphor of the internal clock has been useful for describing and exploring both time estimation and time-dependent behavior, there are—as Wearden points out—some unresolved problems in accounting for all the data available. The chapter by Church et al. shows that even non-human animals are able to combine multiple sources of temporal information. Thus, the question arises, whether one simple clock is sufficient to explain this ability or whether multiple clocks are required instead. The challenge increases regarding human processing of temporal information. While in most of the experiments usually one single response is required, human life provides numerous situations that require several independent temporal adjustments simultaneously (see the chapter by Block). For example, a pianist has to coordinate at least three temporal parameters: the duration of the tones, the changing pitch, and the temporal pattern of the hand and finger movements. Either, the internal clock must be capable of flexible adjustments, or several concurrently operating internal clocks would be needed to account for this ability.

* Helfrich, H. (Ed.). (1996). *Time and mind*. Seattle, WA: Hogrefe & Huber Publishers

Not all researchers take the existence of one or more internal clocks for granted. The contribution by RICHARD BLOCK reveals considerable influences of non-temporal factors, such as the *context* of time judgments and the allocation of *attention*. These influences may not be parsimoniously integrated in an internal-clock framework. It is an open question as to whether these non-timing factors can be treated as “response bias” and behavioral noise to be eliminated from “pure time,” or whether they must be considered intrinsic components of psychological time.

A further challenge for internal-clock models is the question of the specificity of *sensory modalities* and their relation to time. This issue is addressed by the contributions of SIMON GRONDIN and FLORIAN KLAPPROTH. They question whether time perception and time memory are based on a central device independent of sensory modalities, or whether they are an emergent property of the way events are organized within each sensory modality. As Grondin points out, modality-specific timing devices may be adapted to different environmental requirements: Acoustic information such as speech and music is intrinsically based on temporal structure and, therefore, requires finer temporal resolution than optical information for which spatial structure is of crucial importance. This does not rule out the existence of a central timing device, as demonstrated for memory by Klapproth. He suggests an association between modality-specific encoding and a central time memory.

THOMAS RAMMSAYER investigates the neurobiological substrates of temporal processing and thereby tries to support the assumption of two distinct timing mechanisms, one for *short* and one for *long* durations. Based on experimentally induced pharmacological variations in the neurotransmitter systems, he presents evidence that temporal processing of intervals in the range of seconds or more is *cognitively* mediated, whereas processing of brief durations below approximately one-half second relies on automatic *sensory* mechanisms most likely located at a subcortical level.

The neurobiological approach leads to the general question whether these neural structures and functions are specific for time processing or, instead, are common to all information processing. With these considerations, the focus shifts, as Borís Burle says, “from temporal information processing to temporal processing of information.” This issue is the focus of the second part of the book.

Part II: Time as a constituent of information processing

Time is an object of information processing, but it is also a constituent of it. There are at least three reasons, why time is constitutive for information processing. First, temporal structures of distal stimuli are essential for the contents of cognition. Second, temporal patterns of brain activity seem to be closely linked to formation of and attention to objects and events. And, third, each cognitive process is constrained by time limits.

In order to identify objects and events and not to experience the world as chaos, temporal *continuity* as well as temporal *change* must exist. The identity of objects in cognition is ensured only when consecutive elements are temporally integrated but separated from concurrent elements. Moreover, signals arriving from different sensory channels at different times must be synchronized in the brain.

Direct measurement of brain activity using electroencephalography as well as neuroimaging techniques lead to new insights about the ways the tasks of integration and separation are managed within the auditory and the visual modality. ISTVÁN CZIGLER and his colleagues analyze the temporal characteristics of auditory event-synthesis by using the mismatch negativity component (MMN) of event-related brain potentials. They conclude that there is a *temporal unit* of 200 ms (approximately the duration of a spoken syllable) where auditory stimuli are automatically perceived as belonging to the same event. SIMO VANNI and his research group combined temporal resolution techniques (MEG and EEG) with spatial resolution techniques (fMRI) to determine the *temporal succession* of activation in the visual system. Their results suggest that the timing of different areas may best be described as a feedforward-feedback cycle. While Vanni et al. focus on the asynchronous onsets of activity in different brain areas, the concept of *temporal binding* presented by ANDREAS ENGEL emphasizes the transient synchronization of neuronal discharges. Physiological experiments support the idea that the synchrony of neuroelectric oscillations binds together neural activity. This activity is broadly distributed among brain systems, and it is evoked by the various attributes of a stimulus object or another cognitive item. The synchronized short-time activity leads to traces in short-term (working) memory and thus enables the mental representation of objects.

According to contemporary models, working memory extends for approximately two seconds. Within this time span, several different elements can be held present. To account for the simultaneous presence of different elements, a theory of binding by synchrony must describe the time-dependent characteristics of neural processing in order to explain how each single element can be identified reliably and can be discriminated from other elements. ROBERT GLASSMAN suggests that simultaneously operating frequencies share a *harmonic structure*, similar to octave bands in musical information. According to this assumption, the lowest and highest frequencies simultaneously present in working memory share a proportion of 1:2. This mechanism allows the identification of distinct elements in working memory by repetition of each single synchrony. At the same time, the existence of sufficiently different synchronies allows the discrimination of different elements.

Concerning the temporal constraints of information processing, HANS-GEORG GEISSLER and RAUL KOMPASS start with the observation that all perceptual processes share common mechanisms across modalities. The results from several experiments in the field of perception and decision-making lead to the assumption that these mechanisms can best be described in terms of temporal constraints of our brain functioning. It seems that the human brain does not process information continuously but in successive steps of distinct duration, so-called *quanta* of time.

Some researchers have hypothesized that the periodic oscillations unfold on a background of a fixed oscillatory timing mechanism (an internal clock) that produces quanta of time for conscious information processing. According to this model, all cognitive processes (including time estimation) depend on a common neural-beat mechanism, or temporal rhythm. One interesting question is whether there exists a relationship between the frequency of the internal clock and the frequency with which other cognitive processes operate. BORÍS BURLE and his colleagues propose an

architecture model, the kernel of which consists of an internal oscillator pacing both the flow of information and the receptivity state of neurons.

By putting together the different perspectives expressed by the various contributors to the book, an important step on the way towards a unified view of psychological time has been achieved. It can help to bridge the gap between “temporal information processing” and “temporal processing of information,” between time as an object and time as a constituent of information processing.

The book has benefited from the fact that the contributors read and reviewed each other’s chapters. I would like to thank them for this collaborative effort. I also thank Florian Klapproth, Carola Lindner-Müller, and Ulrich Seidler-Brandler who invaluabley supported and advised me in organizing the symposium and preparing the book. Special thanks go to my colleague and husband Erich Höltter, from whom I received indispensable help and support. He not only encouraged me, but also kept track of the ultimate form of the book.

Hildesheim, November 2003

Hede Helfrich

Part I:

Time as an object of information processing

Chapter 1:

Simultaneous temporal processing*

RUSSELL M. CHURCH, PAULO GUILHARDI, RICHARD KEEN,
MIKA MACINNIS, and KIMBERLY KIRKPATRICK

Abstract

There is considerable evidence that animals can time multiple intervals that occur separately or concurrently. Such simultaneous temporal processing occurs both in temporal discrimination procedures and in classical conditioning procedures. The first part of the chapter will consist of the review of the evidence for simultaneous temporal processing, and the conditions under which the different intervals have influences on each other. The second part of the chapter will be a brief description of two timing theories: Scalar Timing Theory and Packet Theory of Timing. Scalar Timing Theory consists of a pacemaker-switch-accumulator system that serves as a clock, a memory that consists of examples of previously reinforced intervals, and a decision process that involves a comparison of ratios to a criterion; the Packet Theory of Timing consists of a conditional expected time function that serves as a clock, a memory that consists of weighted sums of these values, and a probabilistic decision process that produces packets of responses. Both of these theories will be applied to an example of simultaneous temporal processing by rats, and will serve as the basis for some general comments about the selection and evaluation of quantitative theories of timing.

Introduction

Rats, pigeons, and other animals readily learn to make time discriminations in the range of seconds to minutes. Such interval timing is typically demonstrated with fixed-interval procedures, but can also be seen in temporal discrimination procedures in which animals are trained to produce one response following an interval of a short duration and another response following an interval of a long duration (for example, see Stubbs, 1968).

In a fixed-interval schedule of reinforcement, the first response of an animal following a fixed interval of time (such as 60 s) is followed by food. As a result of such training, animals readily learn to respond more rapidly late in the interval than early in the interval (for example, see Catania & Reynolds, 1968). In a standard operant fixed-interval schedule of reinforcement, the fixed interval is defined as the time

* Preparation of this chapter was supported by National Institute of Mental Health Grant MH44234 to Brown University.

from the delivery of food until the availability of the next food. Alternatively, if a stimulus precedes the food, the interval may be specified from the onset of a stimulus until the availability of the next food. Whether the time marker is the previous food or stimulus onset, the next food is delivered contingent upon the response.

Variations on the fixed-interval procedure have been undertaken to determine whether animals can simultaneously time multiple intervals at once. In a segmented fixed-interval procedure (described in further detail below) there are two potential time markers, the event that marks the beginning of the fixed interval, and the event that marks the beginning of a segment. It is possible that an animal can time both the fixed interval and the segment simultaneously. The segmented fixed-interval procedure and its major results will be discussed in the first portion of the chapter.

In a search of the PsychINFO database for the years between 1887 and 2002, only five articles were found in which the phrase “simultaneous temporal processing” appeared in the title or the abstract. The first of these was an article by Meck and Church (1984). The other four articles that used this phrase in the title or the abstract included either Meck or Church as one of the authors (Church, 1984; Meck, 1987; Olton, Wenk, Church, & Meck, 1988; Meck & Williams, 1997). Based on these facts, one might assume that there is little evidence for simultaneous temporal processing, but that would be mistaken. Many standard conditioning experiments contain multiple time markers that can be timed simultaneously. Although most of these procedures were not explicitly designed to produce simultaneous temporal processing, there is ample opportunity for such timing to occur. The second portion of the chapter will discuss the form of simultaneous temporal processing under widely implemented standard conditioning procedures.

The segmented fixed-interval procedure

One variant of the fixed-interval procedure is to add another stimulus during the interval. This procedure, which will be referred to as a “segmented fixed-interval procedure,” has been used for at least three different purposes: as a test of the chaining hypothesis, as a test of the conditioned reinforcement hypothesis, and as a test of the simultaneous temporal processing hypothesis. Although all the experiments to be described used a comparison of a standard fixed-interval procedure with a segmented fixed-interval procedure, they differed in many ways. Procedures were used in which the fixed interval was specified from the delivery of the previous food, and also procedures in which the fixed interval was specified from the onset of a stimulus; in some procedures the onset of a segment was delivered at a fixed time while in other procedures it was delivered following the first response after a fixed time; both pigeons and rats were used; the duration of the intervals differed considerably. The fixed intervals ranged from 50 s to 60 min; the duration of the segment stimulus varied from 0.7 s to 50 s; and the duration of the segments varied from 10 s to 4 min. Despite these differences in durations and the differences in the interpretations of the results, the response gradients in the experiments with the segmented fixed-interval procedures were similar.

As a test of the chaining hypothesis of fixed-interval performance

In a fixed-interval procedure, the mean response rate of the animal increases as a function of time. Although it might be natural to assume that “time” was the independent variable, there has been an extensive and continuing effort to identify the observable, or at least potentially observable, responses that occur during the time interval that may serve as discriminative stimuli. Behavior in a fixed-interval procedure can be characterized as a series of responses, and the assumption is that reinforcement strengthens responses that occurred shortly before its delivery more strongly than responses that occurred earlier. The chaining hypothesis is that each link in the behavioral chain acts as a discriminative stimulus that controls the response rate during the next link. Thus, the series of responses may serve as a mediating behavior between the successive deliveries of food. This is known as the chaining hypothesis of fixed-interval performance (Keller & Schoenfeld, 1950). One test of the chaining hypothesis is to present a stimulus during the fixed time interval that disrupts performance during the stimulus. According to the chaining hypothesis, such a stimulus should also affect the overall increase in mean response rate as a function of time.

In one experiment, four pigeons were trained on a fixed-interval procedure in the first phase and a segmented fixed-interval procedure in the second phase (Dews, 1962). In the fixed-interval procedure, food was available 500 s after the previous food delivery. In the segmented fixed-interval procedure, the houselight was off for 50 s, on for 50 s, etc. throughout the 500-s interval from food until the availability of the next food. This segmented fixed-interval procedure is illustrated at the top of Figure 1.

The results of the experiment are also shown in Figure 1. The independent variable is time in seconds since the last delivery of food; the dependent variable is response rate as a proportion of the maximum response rate. During the first phase of fixed-interval training (open squares with dotted lines), the mean response rate increased as a function of time. This pattern is often referred to as a “scallop.” During the second phase with segmented fixed-interval training, there was a marked decrease in response rate when the houselight was off. The use of a single measure of response rate during each segment obscures any gradient of responding within segments, but gradients following the onset of a segment stimulus can be seen in the results of the next two experiments to be described (Figures 2 and 3).

This reduction in response rate when the houselight was off could have occurred for many reasons. It may have been a disrupter (Pavlovian external inhibition); it may have been because food was never delivered when the houselight was off (Pavlovian discriminative inhibition); or it may have been due to the difference in salience of the presence or absence of the houselight. For the test of the chaining hypothesis, the cause of the reduction in response rate when the houselight was off relative to when the houselight was on was not important. The critical observation was that, during the segmented fixed-interval procedure, the mean response rate in the presence of the houselight increased as a function of time, i.e., the scalloped pattern remained. Apparently, the maintenance of this temporal gradient of responding did not require the maintenance of responding during the time that the houselight was

off. This finding, coupled with the fact that the response rates during the terminal segments were approximately the same in the FI and the segmented FI conditions, was evidence against the chaining hypothesis. The temporal gradient could be maintained in the absence of mediating responses. A series of studies by Dews increased generality for these results and provided additional support for these conclusions (Dews, 1965a, 1965b, 1966, 1970).

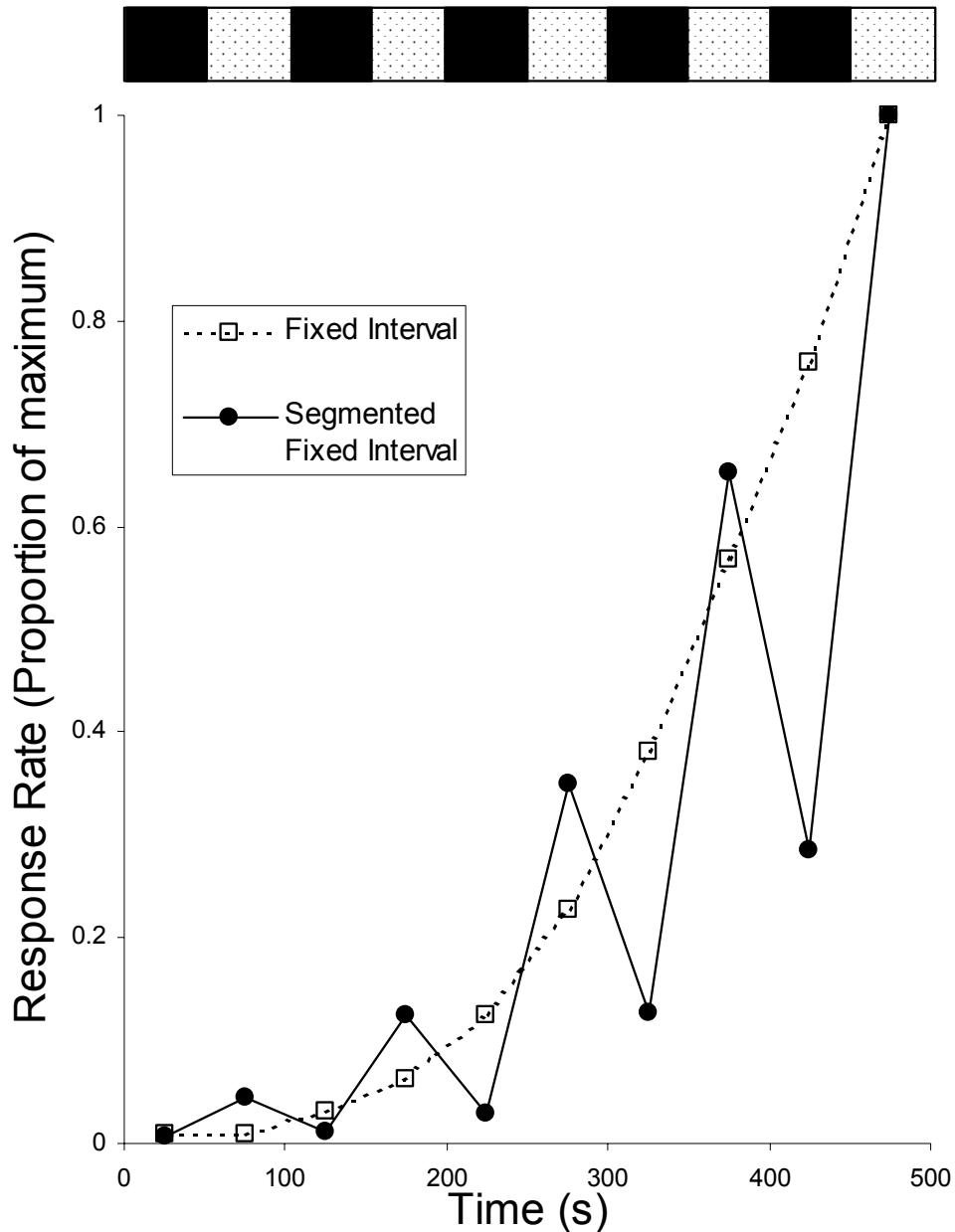


Figure 1: Relative response rate as a function of time since food in a fixed-interval procedure (open squares) and a segmented fixed-interval procedure (solid circles). The segmented fixed-interval procedure is illustrated at the top of the figure: A light was off during the dark intervals and on during the light intervals. Redrawn from Dews (1962).

As a test of the secondary reinforcement hypothesis

A primary reinforcer is normally defined as something that satisfies a biological need, such as hunger. Thus, food is a primary reinforcer. A conditioned reinforcer may be created by pairing a previously neutral stimulus with a primary reinforcer. In the segmented fixed-interval procedure, food is delivered in the presence of one of the segments. Thus, the segment, and others like it, should be conditioned reinforcers and would serve to reinforce behavior. One interpretation of the behavior of animals in a segmented fixed-interval procedure is that the behavior is maintained by conditioned reinforcement.

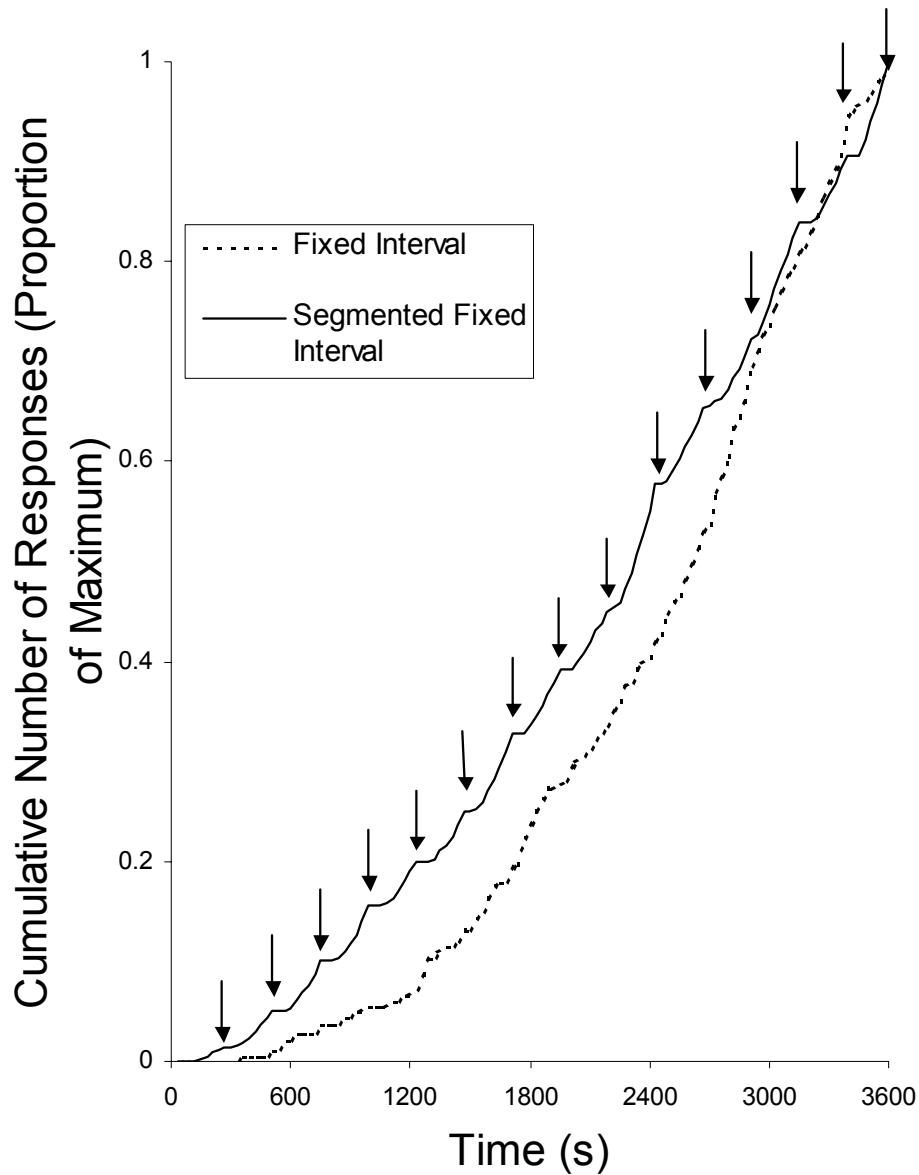


Figure 2: Relative cumulative number of responses as a function of time since food in a fixed-interval procedure (dashed line) and a segmented fixed-interval procedure (solid line). The arrows indicate the time at which a 0.7-s light stimulus was presented. Redrawn from Kelleher (1966).

Figure 2 shows the procedure and some results in one experiment with pigeons (Kelleher, 1966). The independent variable is the time since the last food delivery and the dependent variable is the relative cumulative number of responses (the number of responses during a small interval of time, divided by the total number of responses). The arrows indicate the times at which short stimuli (0.7-s lights) occurred. Each segment stimulus was delivered following the first response after a 4-min interval. The data are taken from only a single 60-min interval for the fixed-interval condition (the dashed line), and from the mean of only two 60-min intervals for the segmented fixed-interval condition (the solid line). The response rate is represented by the slope of the cumulative response function. There was a rising slope in the normalized cumulative response function for both the fixed-interval procedure and the segmented fixed-interval procedure. In addition, for the segmented fixed-interval procedure, response rate was low immediately after a segment stimulus, and then higher later in the 4-min interval.

The main purpose of the experiment was to determine whether or not the segment stimuli could increase relative response rate during a long (60-min) fixed-interval schedule of reinforcement, and whether or not they could lead to the development of a within-segment response gradient. Both of these findings were reported, and they were considered to be supportive of the conditioned reinforcement hypothesis. In other experiments in this article, the segment stimulus was not presented at the end of the last segment which was immediately before delivery of the reinforcer. In these experiments, the response gradients in the segments depended on the pairing of the segment stimulus with the food reinforcement. This supported the interpretation that the segment stimulus was a conditioned reinforcer. However, in a more thorough analysis of the determinants of conditioned reinforcement, Stubbs (1971) did not find a difference in performance between presentation of segments paired or not paired with food reinforcement, even when factors such as the animal's history, reinforcement schedule, and reinforcement rate were analyzed. This suggested that the segmented stimulus served as a discriminative stimulus rather than as a conditioned reinforcer.

As a test of the simultaneous temporal processing hypothesis

Meck and Church (1984) attempted to determine whether rats might simultaneously time the segments in conjunction with timing of the fixed intervals. In the first of the seven experiments the first phase consisted of 35 3-hour sessions of fixed-interval training followed by a second phase with 30 3-hour sessions of segmented fixed-interval training. For fixed-interval training, after an interval of 130 s in a dark box, a houselight was turned on. The first lever response after a fixed interval of 50 s delivered a 45-mg pellet of food and turned off the houselight. These cycles were repeated throughout the session. The segmented fixed-interval procedure was the same, except for the addition of 1-s white noise stimuli that occurred at the time of houselight onset, and 10, 20, 30, and 40 s after the time of houselight onset (as shown at the top of Figure 3).

Figure 3 shows the response rate (expressed as a percentage of the maximum response rate) on the last 20 sessions of fixed-interval training and on the last 20 ses-

sions of segmented fixed-interval training. During the fixed-interval training, the mean response rate had the standard increasing gradient, the fixed-interval scallop. During the second phase with segmented fixed-interval training, there was an overall increase in response rate as a function of time since onset of the houselight, but also a clear decrease in response rate at the onset of the white-noise segment stimuli. In terms of relative response rate, the magnitude of the effect increased as the time of the next reinforcement approached.

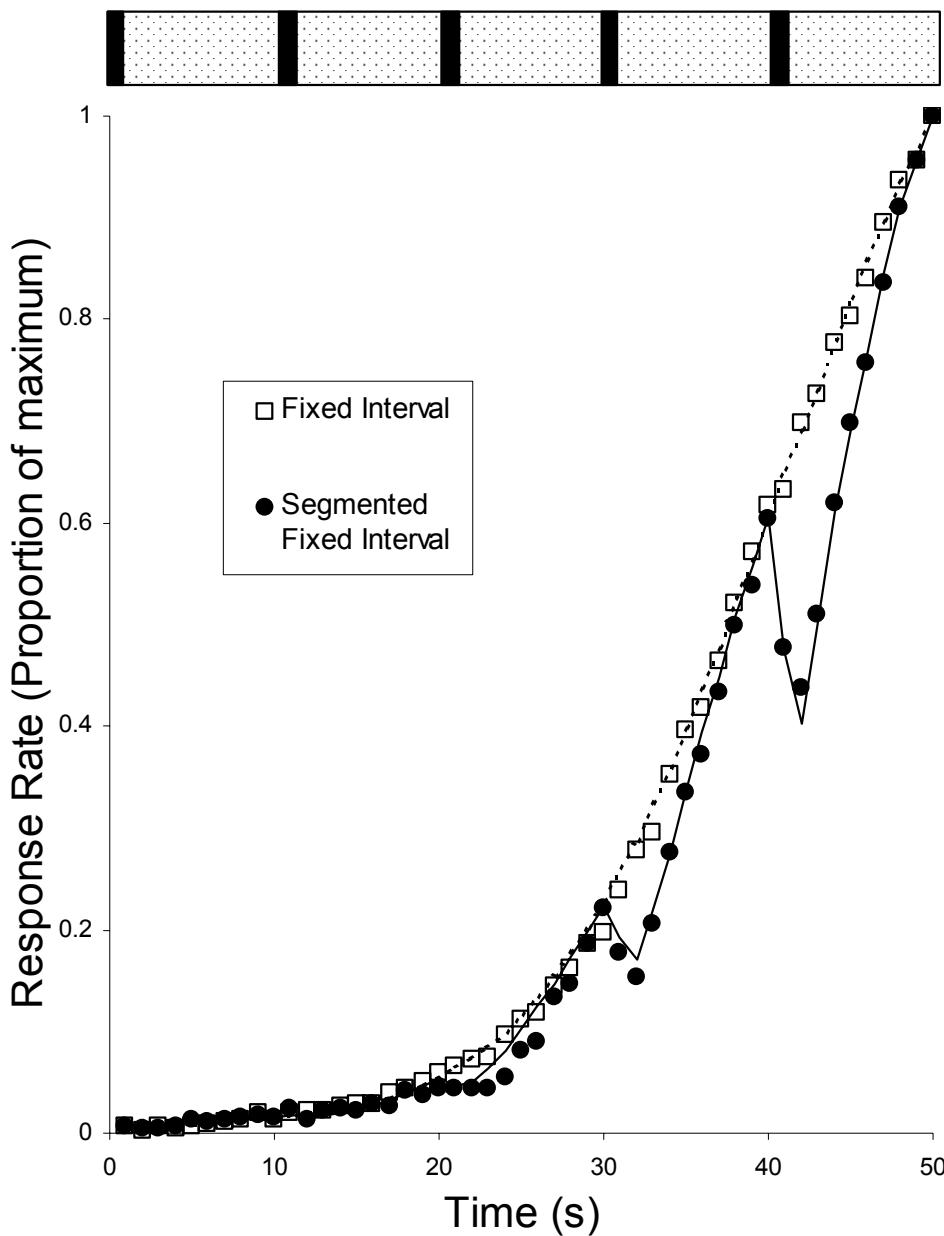


Figure 3: Relative response rate as a function of time since food in a fixed-interval procedure (open squares) and a segmented-fixed interval procedure (solid circles). The segmented fixed-interval procedure is illustrated at the top of the figure: The dark intervals indicate the times at which a 1.0-s white noise stimulus was presented. Redrawn from Meck and Church (1984).

In a second experiment, Meck and Church (1984) repeated the conditions shown in Figure 3, but added one more white-noise segment stimulus during the last second of the interval. The overall and segment gradients were similar to those shown in Figure 3. Other experiments in this article produced similar results with a segmented peak procedure in which the fixed interval and segment stimuli continued beyond the normal time of reinforcement (and reinforcement was withheld), and when the final segment stimulus occurred just before the reinforcer. These results suggest that the onset of the stimulus for the fixed interval, and the onset of a segment stimulus both served as discriminative stimuli for the time at which food would be available.

The main contributions of the Meck and Church (1984) experiments were to describe the problem as one of timing multiple intervals (rather than disruption of a response chain or conditioned reinforcement), and to describe the results of a quantitative model of timing. With this timing perspective it became natural to examine whether the application of scalar timing theory to a single interval could be extended to the timing of multiple intervals. In Figures 1 and 2 the lines merely connected the observed data points, thus facilitating visualization of the pattern of the data. In Figure 3 the dotted and solid lines that were near the observed data points were based on a quantitative theory of timing—scalar timing theory. It is possible that an examination of scalar timing theory will provide some understanding of the basis of simultaneous temporal processing.

Scalar timing theory

The essential principles of scalar timing theory were developed by Gibbon (1977), and they were subsequently used in the development of an information processing model of scalar timing theory (Gibbon, Church, & Meck, 1984). The information-processing model of scalar timing theory contains three major parts: clock, memory, and decision. A clock consisted of a pacemaker, a switch, and an accumulator; the memory was a reference memory for long-term storage of time intervals, and the decision was done by a comparator that could measure the nearness of the current time (in the accumulator) with a remembered time that was sampled from a reference memory. For timing a single interval, all that is needed is a single clock (pacemaker, switch, and accumulator), a single memory, and a single comparator. These parts are shown in the upper left side of Figure 4.

In the fixed-interval procedure mentioned above, when the food was delivered the food onset switch would close, permitting pulses from the pacemaker to enter the accumulator. Thus, if the pacemaker emitted 5 pulses a second with no variability, after 50 s the accumulator would have 250 pulses. If there was some variability in the pacemaker rate, after 50 s the accumulator might have fewer or more than 250 pulses. Reference memory contained a representation of the number of pulses in the accumulator at times that reinforcement had been received in the past. This is an exemplar memory that contains separate representations for each of the past examples. The decision is based on a comparison of the current accumulator value, which is continually increasing, and the value of a random sample of one element from reference memory. The comparator output depends on a ratio comparison of the two inputs (accumulator and memory) and a threshold criterion. If the current accumula-

tor value is close enough to the value of the sample from memory, a response occurs. Details of this model are described in several sources (Church & Gibbon, 1982; Gibbon, Church, & Meck, 1984; Church, 2003). Four sources of variability were implemented in the simulations: the coefficient of variation (ratio of standard deviation to mean) of the clock, the mean and standard deviation of the threshold criterion, and the probability of inattention. An exhaustive search of the parameter space produced optimal values of the parameters of .25, .20, .10, and .01 for the four parameters, and these same parameter values were used in several experiments. This accounted for over 99% of the total variance in the response rate gradients in the fixed-interval condition, which suggests that, if scalar timing theory is correct, the animals were nearly always attentive to the time, but that there was some clock and threshold variability.

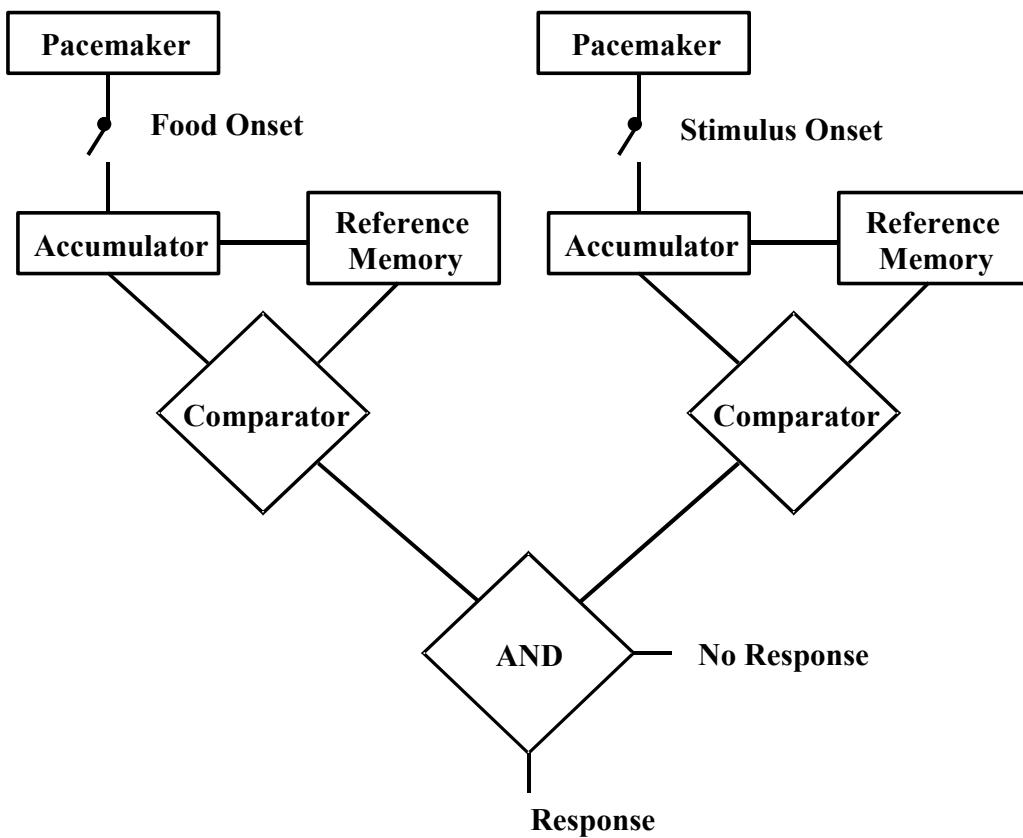


Figure 4: Application of scalar timing theory to the segmented fixed-interval procedure. Two independent clock-memory-decision units are controlled by food onset and stimulus onset. The output of these two units produces a response if both are above a threshold.

In the segmented fixed-interval procedure, the same process with the same parameters was used for the time since food onset, and an equivalent process (but with the addition of a latency-to-close-the-switch parameter, and different parameter values) was used for the time since stimulus onset (the top right part of Figure 4). Thus there was simultaneous timing of the interval since food and the interval since stimulus onset. The output of the two comparators were combined by assuming that the animal attended to the overall interval with some probability, that it attended to

the segment interval with some probability, and that these two probabilities were independent. Thus, on some occasions, the rat attended to both intervals, on some it attended to only the overall interval, and on some it attended to neither. This accounted for over 99% of the total variance in the response rate gradients in the segmented fixed-interval condition, which suggests that, if scalar timing theory is correct, the animals were combining information from the overall and segment intervals in the determination of whether or not to respond.

Simultaneous temporal processing in conditioning procedures

The performance of animals in the segmented fixed-interval procedure makes it clear that they are able to time two intervals simultaneously. Is this an ability that requires a particular test to be revealed, or is simultaneous temporal processing an ability that may be revealed in standard conditions? The purpose of this section is to make the case that simultaneous temporal processing occurs in many conditioning procedures, including the most standard procedures such as delay and trace conditioning. Variations in the location of the reinforcer in a cycle, in stimulus durations, and cycle durations can also be understood as examples of simultaneous temporal processing.

Location of the reinforcer in a cycle

Two types of conditioning procedures studied in Pavlov's laboratory were delay conditioning and trace conditioning (Pavlov, 1927). In delay conditioning, a stimulus is presented for a fixed duration and a reinforcer is presented at the end; in trace conditioning, a stimulus is presented for a fixed duration and a reinforcer is presented at some fixed time after the termination of the stimulus.

The two procedures diagrammed at the top of Figure 5 are variants of the Pavlovian delay and trace conditioning procedures (unpublished research of M. MacInnis). Eighteen rats were trained in a box with one stimulus (white noise), one reinforcer (a food pellet), and one measured response (head entry into the food cup). A cycle consisted of 20 s with noise and 100 s without noise. These cycles continued throughout a session with food available at the same point during each cycle with a probability of 0.5. The data are shown for cycles in which food was delivered. Nine rats received the delay conditioning procedure before the trace procedure; nine other rats received the treatments in the other order. In the case of delay conditioning, food was available at the end of the stimulus on a random half of the cycles (indicated by the first arrow); in the case of trace conditioning, food was available 10 s after stimulus termination on a random half of the cycles (indicated by the second arrow).

The delay procedure provided three time markers (stimulus on, stimulus off, and food delivery). The time from stimulus onset to food availability was 20 s; the time from stimulus termination to food availability was 0 s; and the time from food to food was 120 s. In the delay procedure, the response rate increased as a function of time since stimulus onset; at stimulus termination the response rate declined