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TIME WITHOUT CLOCKS

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Staddon and Higa show that the ability to time events derives from principles of memory rather than from an internal device for measuring the duration of events. This insightful timing theory is parsimonious, fits the data, has potential widespread generality, and is evolutionarily plausible.
Key words: timing theory, temporal control, memory, internal clock

After more than 20 years in the limelight, scalar expectancy theory is in trouble. Not only has it sprouted seemingly infinite parameters that make it inelegantly cumbersome, but the embroidery no longer allows it even to predict Weber's law. Staddon and Higa explain why scalar expectancy theory may be neither internally consistent nor even solidly conceptually based.

Maybe this is the ultimate fate of any theory that firmly maintains its essential truth in the face of all data and simply adds what seems necessary to handle discrepancies. Has such a Ptolemaic endeavor ever worked? Perhaps a successful example can be found in the history of science, but none comes to mind. In psychology, Hullian learning theory also finally fell of its own weight, even though a better alternative never appeared. But, scalar expectancy theory has an even more serious problem. Its seemingly endless collection of cycles and epicycles are replaced by a remarkably simple theory that invokes no timing processes at all. Staddon and Higa not only analyze the shortcomings in scalar theory; their far simpler theory explains more data more precisely. This indeed is an exciting advance in our understanding of how animals deal with timing problems.

Scalar theory never was comprehensive. Staddon and Higa mention that the proponents of the theory have ignored the large body of data available on cyclic interval schedules. Scalar theorizing also has ignored most of the published data on temporal differentiation. The shortcoming was evident even in the first scalar timing paper (Gibbon, 1977), and it has not been remedied since. The theory predicted a linear relationship between the duration of a behavior pattern and the time requirement put on that duration, but the only data discussed were the few that

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fit the prediction. Most of the data showed that the relation actually was described by a fractional-exponent power function (exponents between 0.5 and 0.8 rather than the predicted 1.0), whether the standard was taken as the duration requirement or the durations that actually were followed by the reinforcing stimulus.

Staddon and Higa have accomplished such a perceptive critical analysis of scalar expectancy theory that nothing more need be said. My own comments begin with a reflection on the nature of contemporary behavior theory. Both the Staddon–Higa memory model and internal clock models share an emphasis on what animals bring with them in interacting with their environment, even though they differ in what these processes may be. Hypothesized properties of the animal interact with environmental demands to determine behavior. Behavior-analytic theory has often scrupulously avoided processes internal to the animal. The importance of history in influencing current behavior is well recognized, but history is treated as effects of variables imposed on the animals in the past rather than as those events filtered through an animal. In that type of theory, animals become vehicles for displaying how variables exert their effects on behavior rather than being the processors of environmental events. From the vehicle perspective, invoking either memorial processes or internal clocks is meaningless in explaining behavior. Temporal regularities in behavior are attributed to temporal regularities in the environment, not to the measurement of those temporal events by an internal clock and the translation of those readings into action. Nobody attributes the regularity of a pendulum to the pendulum's time sense or to its memory, so why attribute the temporal regularity of an animal's behavior either to a time measuring device or to a memory process?

But explaining behavior patterns solely as the outcome of the present and past environmental events that result in their appearance is to treat behavior as a purely physical system that is divorced from biology. No biological activity can be understood just by citing the environmental conditions under which it occurs. Explanations require a full understanding of what animals bring with them in their dealings with the environment. The importance of the animal is highlighted in the theory of evolution by natural selection, where animals inherit processes that have enabled their species to adapt to the environment. A biological approach to behavior treats the environment as the poser of adaptive problems that the animal solves with its internal resources. Environments occasion behavior; they do not produce it by themselves.

Memory decay occurs in the animal, not in the environment. As such, it is an inferred process. As a start in identifying its properties, Staddon and Higa draw on the characteristics of habituation, which is defined behaviorally as the waning of reflexive responding to the same stimulus when it is presented repeatedly. Their model to explain habituation, and thereby to explain memory decay in general, invokes other internal processes like reflex strength, a leaky integrator, and memory-trace strength, all tied together into a relatively simple and straightforward quantitative model. They go on to extend their approach to a multiple-time-scale model that follows the same principles. The result of even their preliminary efforts is the ability to integrate a considerable range of phenomena with this plausible model of event memory.

Why is this model any better than one based on an internal clock? One reason is that the memory model pulls together what would appear to be unrelated data without any need to introduce a novel concept such as an internal clock. The internal clock concept has been invoked only in the context of temporal control, whereas the memory model has much broader scope. That it can explain the timing data without reference to an internal time measuring device is both unexpected and impressive. Another reason is that the memory model contains intrinsic non-ad hoc principles for explaining why timing, as well as other behavioral phenomena, should differ substantially depending on the precise conditions under which it is studied. Theories based on internal clocks, which have largely ignored such data, probably could deal with these experimental results only by invoking arbitrary fitting parameters. A third reason is that consideration of the evidence suggests that organisms have not evolved with an internal clock that they use to judge time. The remainder of this paper deals with that issue.

An internal clock presumably records the duration of events and allows behavior to adjust to those durations. The focus of the Staddon–Higa paper is on interval timing, that is, on the animal's ability to judge the duration of a stimulus or to estimate the time between successive events (Carr & Wilkie, 1997). Evolution probably did not have our laboratory procedures in mind when designing a clock to handle interval timing. Evolution had no way of ''knowing'' what events would have to be timed and what the specific intervals might be. So, if the laboratory taps into abilities and processes that influenced survival and reproductive success in the history of the species, our procedures must invoke interval timing processes that evolved for handling other situations in which the events to be timed were essentially arbitrary and thereby unpredictable from one individual to the next. If the same clock services all or even many of these potential situations, it must operate independently of the particular events being timed. An alternative is that the clock is domain specific rather than domain general. If that is the case, theories based on a general-purpose internal clock are simply inadequate to cope with reality and at best must be qualified in terms of the situations to which they apply. Existing theories based on internal clocks seem to opt for enough domain generality as to make them blind to the possible need for such qualifications. The consequence is that consistency in the property of the internal clock should appear across different situations.

The following data are discussed in detail elsewhere (Zeiler, in press), so are only summarized here. Temporal differentiation requirements have been applied to different kinds of behavior. In every case, the particular response or sequence produced different conclusions about temporal differentiation, and different temporal properties of the same response yielded different conclusions as well. A similar divergence in characteristics of timing has been seen when different aspects of behavior are considered in the peak procedure. That is not all. Most experiments have shown that the properties of timing in temporal differentiation did not correspond with those seen in temporal discrimination. This was also the case with differentiation and discrimination versions of the temporal bisection procedure. When the durations to be bisected were raised to a power such that these power means matched the bisection point, the majority of discrimination procedures yielded positive exponents, but differentiation procedures yielded negative exponents. Experiments on both temporal differentiation and temporal discrimination have compared behavior in closed and open feeding economies. In either case, properties of timing varied considerably, and functions even reversed their direction depending on the particular feeding economy. For example, Weber fractions rose with longer time requirements in the open economy, but they decreased with longer requirements in the closed. All of these results sound more like domain specificity than an evolved interval timing system driven by a general-purpose internal clock.

Such observations fit the hypothesis that a general-purpose mechanism for dealing with interval timing has not evolved or, if ever present, did not survive over the course of biological evolution. Why should such a mechanism have evolved? It is not easy to find examples of a serious need for interval timing in the everyday life of humans, and it is even harder to come up with examples of interval timing in other species. Basic biological functioning does not require animals to keep track of time, because other stimuli are available to indicate when to eat, when to sleep, when to wake up, when to mate, when to avoid predators, or when to tend to offspring. The situation is quite different for humans, but that is because of their unique dependence on certain types of social interactions. People need to know about time in order to coordinate their behavior with others, yet people do not do very well in meeting their temporal needs without the support of external mechanical or electronic timekeeping devices. ''Without [a common language of time measurement] and without general access to instruments accurate enough to provide uniform indications of location in time, urban life and civilization as we know it would be impossible. Just about everything we do depends in some way on going and coming, meeting and parting'' (Landes, 1983, p. 2). But even social animals like chimpanzees and gorillas do not seem to schedule meetings or meet their children based on temporal considerations. Concern with time is distinctly human, and the necessary internal devices for meeting such demands are either nonexistent or are grossly inadequate. Astronomers and navigators always needed to know about time, but their own inherent resources could not do the job satisfactorily. If we could deal with time adequately without them, watches and clocks would not be so important to us.

I am suggesting that an internal clock for judging and measuring time never evolved at all. Maybe mechanisms for judging time intervals never existed to be selected and refined, or maybe an incipient internal clock was uneconomical because it served no important purpose. So how can the animals in our experiments display such lawful behavior when subjected to temporal demands? What Staddon and Higa have shown so eloquently and rigorously is that a clock for interval timing is unnecessary for animals to show the kind of behavior that others have interpreted as indicative of control by time. The general processes of memory are sufficiently flexible and powerful to produce such apparent sensitivity without reference to any sort of specialized timing system. This is a major breakthrough in our understanding of how behavior comes under temporal control.

Staddon and Higa have taken a big step forward in the direction of an economical and general theory of operant behavior. Their ability to deal with timing without an internal clock may well lead to a comprehensive domain-general theory of adaptive behavior and thereby does not require specialized processes for each situation. The future is bright, albeit clockless.

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