The Internal Clock: A Manifestation of a Misguided Mechanistic View of Causation?

Matthew L. Eckard¹ • Kennon A. Lattal¹

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Abstract

Across various subfields within psychology, mechanistic causation is invoked regularly. When the temporal contiguity of the typical cause–effect relation is violated, mechanistic causation often assigns causal roles to mediating hypothetical constructs to account for observed effects. Two primary consequences of mechanistic causation are that 1) the proposed hypothetical constructs add what many behavior analysts consider an unnecessary step in the causal chain, and 2) these constructs then become the focus of study thereafter diverting attention from more accessible “causes.” Constructs do not contribute directly to determining the control of behavior; thus, their reification as “causes” often distracts from variables that do fulfill a causal role. In this review, these consequences are discussed in relation to theories of interval timing proposing an internal clock. Not only has this clock been said to be a cause of behavior in experiments on temporally regulated behavior, but also the clock itself has been a frequent subject of study within the timing literature. Despite descriptive accounts of this sort initially serving a heuristic function for model development, the promotion from descriptive aid to causal factor has the potential to limit much of the heuristic value that mechanistic models of causation can provide to the analysis of behavior. Problems related to construct reification are less likely to be at issue when functional relations and the processes of establishing such behavior are emphasized as alternatives to mechanistic causation alone.

Keywords Radical behaviorism · Functional relation · Internal clock · Mechanistic causation

Some behavior analysts (e.g., Chiesa, 1994) have suggested that contemporary psychology often conceptualizes its subject matter by using links-in-the-chain, mechanistic

✉ Matthew L. Eckard
mleckard@mix.wvu.edu

¹ Department of Psychology, West Virginia University, 53 Campus Drive, P.O. Box 6040, Morgantown, WV 26506, USA

models of causation. To explain or account for an effect of the environment on subsequent behavior, this type of mechanistic theorizing often places some type of mediating structure or entity between a potential cause (change in the environment) and its supposed effect (change in behavior). Although it is not an essential aspect of mechanistic causation, this type of causation tends to be invoked when there is some temporal delay between cause and effect (see, e.g., Baum, 1973). One area of experimental research and theory within animal learning that has employed this chain-like causation regularly is research on the “internal clock” popular in interval-timing theory (e.g., scalar expectancy theory; Gibbon, 1977). Despite well-intentioned accounts of this sort beginning as helpful metaphorical aids in describing some particular behavior or pattern of behavior, the hypothesized mediating entities often somehow migrate from being descriptions or metaphors of the behavior to becoming reified and morphing into its cause. The change in theoretical status of these mediating hypothetical entities elevates them to the primary variable of interest to be studied rather than the dependent variable that they were invented to help describe (i.e., behavior) at a more general level.

In this review, the issue of how causation is conceptualized within psychology is addressed, with specific attention to theories of timing. Timing is the main concern here because of its contemporary popularity in experimental psychology and its general relevance to the discussion of causation in explanatory accounts of behavior. First, a brief description of how the philosophy of radical behaviorism views the concept of causation will be presented. Then, causation within timing theories will be considered from this framework, and its relation to a radical behaviorist stance will be addressed along with some of its implications and shortcomings. The review concludes with some remarks as to how radical behaviorism might deconstruct “timing” so as to avoid, inasmuch as possible, the conceptual pitfalls of mediating constructs. It is not unobserved constructs themselves (e.g., the internal clock) with which issue is taken. Constructs serve several useful functions primarily acting as temporary guide posts to help scientists more effectively wade through pockets of ignorance (Zuriff, 1985). They provide a structure onto which wide-ranging experimental phenomena can be organized. The central view here, however, is that once their heuristic function is exhausted and the facts laid out, the influence of these constructs in formulating causal accounts should be diminished greatly if not removed entirely. In other words, once the circumstances “driving” constituent parts of the “clock” is known, why refer to the clock at all?

Causation in Radical Behaviorism

In general, radical behaviorism holds the view that the prediction and control of behavior can be accomplished by studying an organism’s behavior in relation to experienced environmental events without causal reference to states of mind, so-called inner events, or any other intervening entity inserted between the environment and behavior. Radical behaviorism asserts that *hypothetical* inner events observed by the behavior do not reveal anything about the determinants of behavior. Any such hypothesized but unmeasured events sometimes are considered instances of behavior in themselves, and thus, do not differentially fulfill a causal role in explaining an organism’s interaction with its environment. Because it endorses a subject matter that is

consistent with other natural sciences, radical behaviorism considers accounts of behavior based on inner events as lacking the necessary dimensions required of a natural science. Instead, it advocates for a science of behavior in which behavior itself is the basic scientific datum. Thus, radical behaviorism designates the organism's behavior as the primary dependent variable and the organism's history of interaction with the environment as the primary independent variable. Radical behaviorists search for the environmental variables of which behavior is a function (Skinner, 1953).

However, as close as radical behaviorism wishes to be to the natural sciences in terms of the variables it manipulates and measures, it deviates from the physical sciences in its concept of causation. Because the concept of causation with regard to behavior has been controversial for some time, spanning different topics and orientations (see Grünbaum, 1952; von Glasersfeld, 1990), a distinction will be made here between mechanistic causation and functional relation (Chiesa, 1994). This distinction seems particularly germane to theories of interval timing.

Although there are many definitions of mechanism, the one of concern to many behavior analysts is that of likening behavior to the operation of a machine (e.g., Morris, 1988; see also Marr, 1993). A machine is made up of certain constituent parts that, when assembled correctly, allow the machine to function properly. If something were to go into the machine at one end (input), then the output of the machine would be a reliable product at the opposite end. When the machine malfunctions, the malfunctioning piece can be identified and modified accordingly. In this case, one might ask, "What was the *cause* of the malfunction?" and a technician might answer, "The hydraulic-fluid hose cracked, allowing pressure to escape." Mechanistic causation seeks to identify "the 'link' immediately preceding the cessation of movement" (Hanson, 1955, p. 309). This type of causation does not raise many conceptual concerns when discussing things like mechanics and many natural events, as the links in the chain with regard to these phenomena often are directly discernable. The issue arises when this type of causation is attributed to "psychological" phenomena. Mach (1893) warned against integrating causal modes from one science into another:

It would be equivalent, accordingly, to explaining the more simple and immediate by the more complicated and remote, if we were to attempt to derive sensations from the motions of masses, wholly aside from the consideration that the notions of mechanics are economical implements or expedients perfected to represent *mechanical* and not physiological or *psychological* facts. If the *means* and *aims* of research were properly distinguished, and our expositions were restricted to the presentation of *actual facts*, false problems of this kind could not arise. (p. 507; emphasis in original)

One interpretation of Mach's passage is that a mechanistic approach to understanding animal behavior eventually may begin to ignore causes extended in time and instead exclusively focus on immediately preceding links. Thus, mediating constructs, like the internal clock, may be viewed as increasingly valuable in an account of behavior. Links-in-the-chain, mechanistic causation assumes that the chain "has an identifiable beginning and end, *each link is contiguous in space and time*, and [it] illustrates causation as a unidirectional linear process" (Chiesa, 1994, p. 107; emphasis added). This type of causation may be useful in practice where the events constituting the chain

are easily identified; however, a problem arises when the assumption of contiguity of space and time in causation is violated, as is common in the study of behavior.

On the one hand, when the contiguity of space and time between cause and effect is violated, the cause is usually said to change. For example, when a light flashes in an operant chamber and a rat presses the lever immediately, one may be tempted to say that the light caused or occasioned the lever response. On the other hand, when a math problem is placed in front of a student and she writes her answer after some time has elapsed, some are more than tempted to say that an inner thought process was the cause of the answer given and not the math problem itself, along with the student's past history in mathematics training. In this example, one of two temporal gaps can be focused upon to search for functional relations. The first is the time between the presentation of the math problem and the answer given. The second is that spanning the learning of mathematics and performance on the current math problem. Radical behaviorism favors the latter gap, because this gap is often filled with many distinguishable behavior–environment interactions that are amenable to a behavioral analysis. In the case of mechanistic causation, when a temporal gap between an environmental change and a response occurs, something needs to fill that gap. What ends up filling that gap, then, typically is viewed as being part of the causal chain in the account of the subsequent behavior. Furthermore, for reasons discussed later, this mediating link in the chain often takes precedence over earlier, more discernable links. The mechanist would say, “if events at a distance show functional relatedness . . . there must be between those events a sequence of other events, some medium, structure, or mechanism, that connects them” (Chiesa, 1994, p. 131). When adopting a mechanistic view of causation when dealing with behavior, however, this view typically results in either a reductionistic approach to explaining behavior (e.g., ascribing, attributing the cause of behavior to usually unknown physiology) or the creation of a hypothetical construct like “mind” or “intuition” to aid in filling the temporal gap. In either case, Skinner noted that this likely leads to an “explanation of an observed fact which appeals to events taking place somewhere else, at some other level of observation, described in different terms, and measured, if at all, in different dimensions” (Skinner, 1999a, p. 78). In other words, the causal influence on behavior strays from identifiable environmental events and toward hypothesized entities or physiological mechanisms, which then assume causal roles. Mechanistic thinking within psychology deters the study of behavior for its own sake to the relegation of behavior to merely a reflection of or an appendage of what becomes the primary focus of subsequent analyses—an underlying process within the organism, Ryle's (1949) “ghost in the machine.”

In relation to radical behaviorism's goal of behavior itself being the primary subject matter of psychology, reference to a determinant outside the level of behavior, either “down” to physiology or “up” to the mental faculties, is to be approached with skepticism (Skinner, 1999c). Instead, radical behaviorism adopts the concept of functional relation as opposed to the concept of cause and effect. Cause is phrased as a change in the environment and effect is phrased as a change in the organism's behavior (Skinner, 1953). Thus, Mach's (1893) functional relations are endorsed by Skinner, such that radical behaviorism submits that a “full description of [behavior] is taken to include a description of its functional relation with antecedent events . . . extending from the behavior itself to those energy changes at the periphery which we designate as stimuli” (Skinner, 1999b, p. 433). In other words, behavioral processes are perhaps best

investigated with respect to the necessary and sufficient conditions to bring about a pattern of behavior without premature speculation about *how* those changes come to be. Systematically varying one or more experimental parameters often will uncover equally systematic changes in behavior, which constitutes a functional relation (Sidman, 1960). Because radical behaviorism relies on functional relations, it is not drawn into explaining links in a causal chain or hypothesizing presumed processes within the organism to identify *the* cause of behavior. Causality, to the extent that is useful at all, then becomes a relative rather than an absolute question: one of selecting a level of analysis that allows the investigator to best fulfill the demands of the research program and achieve the pragmatic goals of prediction and control of behavior. Of course, physiology is a necessary element in the behavior of any living organism but acknowledging this does not require or even invite reduction of behavior to physiology, that is, explaining the behavior under study as being caused by/reduced to physiology. Physiology is necessary for behavior, but it is not sufficient. It takes an environment to mold the physiology to the extant contingencies. Behavior does not reduce to either physiology or, for that matter, the quasiphysiological entities sometimes invoked in psychological analyses of behavioral phenomena.

The Internal Clock

As mentioned above, it is common in mechanistic causal models in psychology, when there is a temporal gap between an environmental “input” and a behavioral “output,” to invoke hypothetical events that become the links a causal chain “connecting” the input and output. Within interval-timing research, this immediately preceding link is an internal clock, not apparent from direct observation of behavior, but inferred and described mathematically to include parameters coinciding with how a tangible, actual clock functions.

Clocks were developed to aid in measuring the time between events in the external world. At first, the sun itself was used as a clock marking the amount of sunlight left in a day relative to its height above the horizon. Over centuries, the measurement of time progressed from sundials and hourglasses to crude and later sophisticated mechanical and, even later, atomic clocks. Clocks are a useful, ubiquitous aspect of human functioning with a particular importance for planning and executing certain behavior (e.g., taking a turkey out of the oven so it doesn’t burn, leaving for work before traffic gets backed up). Interval-timing theories propose that these same kinds of clocks exist inside the organism. Moreover, not only does this internal clock consist of specifiable parts with specific functions that can be elucidated by experimentation, but also it is said to be directly responsible for behavior in situations where it is optimal to respond according to the passage of some interval of time (Church, 1984).

The classic internal clock, first proposed by Treisman (1963), is said to have similar properties to clocks in the external world. Roberts and Church (1978) indicated, for example, that the clock can be temporarily stopped, it can time intervals of different lengths, it can be reset quickly, and it can time signals from different modalities. These properties are inferred from quantitative relations between a trained animal’s responses in relation to the passage of time during a testing trial or interruptions in the

environment during that passage of time. In a popular information-processing model of interval timing (e.g., Gibbon & Church, 1984), an internal clock is conceptualized as consisting of a pacemaker, a gate, and an accumulator. Each part is said to have a specific function relative to the animal's cognitive function and resultant behavior. The pacemaker produces pulses, the temporal distribution of which can be described by a Poisson function, during baseline conditions in which it is optimal to respond according to some time interval. When a given temporal cue to start timing is introduced into the environment, these pulses are then gated to an accumulator. At the time of reinforcement (i.e., the end of the to-be-timed interval), the number of pulses in the accumulator functions as a representation of the interval and is stored in reference memory for later retrieval. During subsequent trials, the number of pulses stored in reference memory are continually compared to the current number of pulses being accumulated in the current trial. When the two values are "close enough," thus breaching a threshold, responding occurs.

The Clock is Assumed

Before discussing the questionable causal model of an internal clock and its implications, some concerns regarding the basic formation of this internal clock should be addressed. First, the internal clock is assumed: "If we assume that response rate reflects clock setting, then the change in rate reflects the resetting of the clock" (Roberts & Church, 1978, p. 335). This quotation was taken from a section discussing a decrease in response rate being the result of food being presented in the middle of a fixed-interval schedule (Ferster & Skinner, 1957). In what way is a decrease in response rate evidence for an internal clock? It must be taken that this clock has some essentialist importance: "the rat's clock was *designed* to measure times on the order of seconds" (Roberts & Church, 1978, p. 336; emphasis added). The clock is given its existence from implicature speculation. Second, the presumed behavior of "interval timing" has been taken as an isolated internal process itself with the internal clock as the transducing structure, whether conceptualized as physiological or cognitive (Allman, Teki, Griffiths, & Meck, 2014). This view is supported by neurological evidence of oscillations in prefrontal brain regions and dopamine-specific pathways (e.g., the nigrostriatal pathway) in relation to an elapsing interval (see Matell & Meck, 2004; Meck, Penney, & Pouthas, 2008, for reviews). In light of physiological evidence concerning biological instantiations of the different clock components (Meck, 1996), which certainly, and unsurprisingly, reveals functional relations between physiological manipulations and subsequent behavior, it perhaps is worth highlighting the view that the "internal clock" exists in the model, not in the neural tissue. Thus, it would seem as though the internal clock can take on different identities and formulations depending on the orientation of the scientist—either cognitive or neurological. Indeed, as noted above, identifying raw physiology itself as a mediator of behavior given sufficient environmental context may be valid. However, developing a construct before the physiological evidence is available (Treisman, 1963), and then reifying the construct through later advances in physiology (e.g., Matell & Meck, 2004) appears to be invoking material causation using a mechanism (i.e., the clock) that is inherently immaterial. There is little support for the position that timing exists as a clock property independent of its environmental

surround. The clock must be “programmed” by reinforcement (Killeen & Fetterman, 1988), or the subject must at least be taught how to access such a clock. Furthermore, even though precise and accurate responding occurs on a fixed-interval schedule or in the peak procedure (Catania, 1970), this does not *prima facie* reduce the control of such performance to physiological processes except in the most basic sense that all behavior ultimately is grounded in physiology. This state of affairs can be compared to the concept of reinforcement, which in some sense obviously is mediated by physiology of the brain and other organs, neither of the latter “explain” what will be reinforcing or the ways in which reinforcers have their behavioral effects.

An argument can be made that mathematical or physiological reification substantiates constructs like the internal clock. This reification promotes the *existence* of a construct from being assumed to being actual, which then leads to the construct being ascribed causal properties. In this way, psychology often follows in the footsteps of physics, be it for better or worse. Unlike physicists, though, psychologists often “bring to their theorizing a wealth of prescientific concepts about human action derived from everyday speech, intuition, and their own phenomenology” (Zuriff, 1985, p. 74). A focus on structure over function within psychology coupled with a propensity to look for causes inside the organism often creates the conditions in which constructs (in our view, nonphysical metaphors) are proposed as mediators, which then become reified through the process sometimes labeled “physiologizing.” Although this may be interpreted as a simple argument of semantics, one can readily see how the use of metaphor (like the clock), because of its simplifying action, can dictate the future behavior of scientists (Hineline, 2004).

The Problem of Mechanistic Causation

The internal-clock model of interval timing highlights some of the potential drawbacks of relying on mechanistic causation when attempting to account for behavior. These drawbacks center on very practical concerns for psychology as an experimental and theoretical enterprise. When psychologists identify a new behavioral phenomenon, a question they are likely to ask might be “Of what variables is this phenomenon a function?” Further study would likely lead to determining the variables responsible for this novel phenomenon. As a result of this process of variable identification and enumeration, a particular theory likely will be developed to condense the relations between these variables into general principles or behavioral laws and theorems. To the extent that these variables potentially can be directly manipulated or observed, and orderly data are obtained, the theories will be considered valid and reliable. To the extent that these theories are valid and reliable, they potentially can be used for practical action in the world for prediction and control of behavior (Skinner, 1953).

With regard to the theories invoking the presence of an internal clock, it could be argued that this mechanistic internal-clock model has two substantial implications regarding the variables studied and the resulting focus of study or theory thereafter. First, it adds to the number of variables to be accounted for (Chiesa, 1994). It already has been noted that when a temporal gap is present between a cause and an effect, mediating structures or entities, much like an internal clock, are invoked as additional variables to explain the cause–effect relation. Thus, the presence of the internal clock

forces the committed scientist to consider an additional step in the causal chain. Skinner (1953) identified this additional step as the unrequired second link in the chain: “In each case, we have a causal chain consisting of three links: (1) an operation performed on the animal from without . . . (2) an inner condition . . . and (3) a kind of behavior. . .” (p. 34). Skinner went on to note that if the third link is functionally related to the first, then we can disregard the second link as a superfluous addition to an otherwise parsimonious account of behavior. In some instances, there may be value in investigating the second link in this chain; however, to the extent that the second link is represented by a hypothetical entity, the intensive work that follows may be for naught.

This second link is only useful in an experimental analysis of behavior if it can be manipulated. Timing theorists do suggest that we can alter this internal clock—the pacemaker rate, for example—but only by introducing external stimuli (e.g., changes in reinforcement rate; Killeen & Fetterman, 1988). If the only methods by which to manipulate this internal clock come from outside the organism and the only evidence for this internal-clock manipulation is behavior, then there is a direct link between the first and third link of Skinner’s causal chain. The addition of the internal clock in the second link only complicates an otherwise clear functional relation between environment and behavior.

The second implication of mechanistic causation is that these added variables (i.e., the internal clock) become the focus of subsequent study (Chiesa, 1994). Like most cognitive models of some “inner working,” the internal clock is assumed to mediate the interaction between behavior and environment. Also, because the internal clock is largely derived from theoretical quantitative models of timing, the search for the relevant parameters requires extensive study. To this end, the clock itself and the relation between its constituent parts have become the focus of the research relegating behavior and behavior–environment interactions to the back burner, as it were. Radical behaviorism would abstain from implicating such an entity because it “diverts attention from specific properties of behavior and the context in which it occurs, obscuring relations *actually* taking place by focusing on relations *assumed* to be taking place.” (Chiesa, 1994, p. 153; emphasis in original). Evidence of this diversion of attention from describing the behavior of the animal to describing the faculties of its cognitive apparatus is apparent. For example, Church and Deluty (1977) stated, “[t]hese facts of temporal discrimination suggest that the rat has some sort of internal clock which it can read. The quantitative results of this experiment reveal some of the properties of this internal clock” (p. 223; see also Allman et al., 2014, for a more recent review of the internal clock). Furthermore, not much attention is given to how an animal might learn to read this clock, and whether that hypothesized process is the same as, or even more parsimonious than, learning as a result of behavior–environment interactions. If variables like the clock are to be included in a science of behavior at all, then they are only to function as a tentative means to an end, not the end in itself. For example, they may provide a useful heuristic framework from which to view behavior that is sensitive to the temporal properties of reinforcement (see Richelle & Lejeune, 1980, for a brief discussion). Invoking constructs like the internal clock, however, as a *cause* of behavior distracts and deflects the focus of the analysis from the environment or organism’s learning history as sources of the controlling variables of behavior.

From this diversion, different theories have emerged in an attempt to refine further the clock or to offer different viewpoints on the functions of the clock. Because

conceptions of the internal clock differ from theorist to theorist, these theories undergo a Darwinian-like selection process by which the assumptions of one model are pitted against the assumptions of another in a battle of “variance accounted for.” Skinner (1999a) noted that research designed with the goal of theory validation often is conducted in vain. One could argue that the selection process of theories reflects the progression of a science, and that the hypothetico-deductive method should be praised as such. However, when such a theory begins to dictate the research as opposed to the data controlling the subsequent research, there is cause for concern (Bachrach, 1962). Also, because theories of the hypothetico-deductive type often invoke processes or entities that are hypothetical, they can often be manipulated at will to fit the scientist’s needs (Skinner, 1953).

Hypothetical Construct or Intervening Variable?

It may well be that these theories, although stating that the animal *has* an internal clock, are suggesting that the animal is behaving *as if* it had a clock that it does or does not consult. In this case, the internal clock is not necessarily said to be causing the behavior. On the contrary, the clock may be being used as a metaphor to describe the behavior. This situation may be conceptualized in terms of the discussion of intervening variables and hypothetical constructs by MacCorquodale and Meehl (1948). They postulated that to qualify as an intervening variable, the hypothetical term in question must be strictly deducible from the mathematical expressions that define it. The mathematical expressions in turn derive from functional relations between empirically (experimentally) interrelated independent and dependent variables. Described differently, the assumptions of the model must be strictly derived from the mathematical expressions. In relation the present argument, if any properties of the internal clock must be necessarily assumed *a priori* for their existence, then they do not qualify as summarizing intervening variables. It already has been noted that from one of the original descriptions of the clock given by Roberts and Church (1978) that the variables that constitute the clock are unmistakably assumed. Likewise, Gibbon (1977) suggested that this timing theory is one in which “a specific *translation mechanism* is proposed which regards behavior in time-correlated experimental paradigms as reflecting expectancies of reward. . .” (p. 281; emphasis added). He went on to say that, “it will be seen that different constructions of the timing process may be differentiated only when standard deviations as well as means are considered” (p. 281). Thus, Gibbon indicated that behavior is the measure by which this internal clock is invoked, but it is still the case that the clock itself is not deducible from the means and standard deviations that are calculated from the behavior.

This is not to say, however, that theories involving internal clocks, pacemakers, and the like are without value. As MacCorquodale and Meehl (1948) suggested, it certainly is useful to have condensed terms and expressions by which to refer to a behavioral phenomenon like “timing.” Skinner adopted a similar view of this type of theory construction: “Beyond the collection of uniform relationships lies the need for a formal representation of the data *reduced to a minimal number of terms*” (Skinner, 1999a, p. 107; emphasis added). The notion of a reduction to a minimal number of terms seems to suggest that a theory postulating relations between basic processes as a tool in the

prediction of behavior certainly has a place in radical behaviorism. Likewise, the mathematical expressions specifying certain processes of the clock help parsimoniously describe relatively cogent functional relations between the intervals of time experienced by the animal and its behavior under the scheduled contingency. The expressions themselves could be viewed as containing parameters that may be considered as intervening variables to help describe the functional relation between environmental stimuli and subsequent behavior. But even to this end, there are various mathematical expressions of the internal-clock process in which the parameters constituting them are reducible to neither behavior nor stimulus properties. This is inconsistent with Skinner's formulation of how a theory of behavior ought to be constructed in that the "construction will not refer to another dimensional system. . ." (Skinner, 1999a, p. 107). In the present case, the clock and its various expressions constitute a dimensional system outside the level of environment–behavior interactions. It is easy to assign to these expressions "certain existence propositions which would automatically make [them] 'hypothetical' rather than 'abstractive'" (MacCorquodale & Meehl, 1948, p. 601; "abstractive" is another term for intervening variable). For example, Gibbon and Church (1984) gave an account of what might be contributing to variation in the behavior of animals on a particular psychophysical procedure. To account for within-subject variance on this procedure, they highlighted variance in the pacemaker pulse rate, the early or late closing of the switch, or intervals in the memory comparator being "close enough" to the current interval all as plausible accounts for this behavioral variation. They then went on to provide mathematical accounts of how one might conceptualize the influence of these variables in the variation of behavior. In this case, the variation in behavior is not described in terms of the organism's learning history or the nature of the stimuli used. Thus, the clock is not deducible from the models used to describe it, and the variables in these models are not strictly anchored to either the animal's behavior or characteristics and histories of interaction between behavior and environmental stimuli. That is, in MacCorquodale and Meehl's (1948) formulation, the clock has the surplus meaning associated with hypothetical constructs.

To be clear, this analysis is not intended as an affront to mathematical models of behavior or even hypothetical constructs, *per se*. Quantitative accounts of behavior and hypothetical constructs have proven useful in integrating data across experiments and laboratories by pointing to higher-order behavioral processes (e.g., Nevin, 1984). Likewise, radical behaviorism includes the view that "a theoretical construction may yield greater generality than any assemblage of facts" (Skinner, 1999a, p. 107). They do, however, introduce conceptual problems when used in certain ways, as they are in timing. In many instances within behavior analysis constructs have proven valuable so long as they are kept within the guidelines laid out by MacCorquodale and Meehl (1948): do not reify, do not "physiologize." Moreover, like physiological accounts, mathematical accounts do not necessitate that the hypothetical construct become a "thing" to be performing the action—the cause of the action. Recapitulating viewpoints described by Zuriff (1985) and Hineline (2004), Machado (1997) pointed out that, "[i]n some environments, [changes in behavior] yield behavior the properties of which lead human observers to talk about clocks" (p. 258). Put another way, if an animal's behavior aligns well with temporally spaced events, one may be tempted to say that the animal is "timing" the events as if it had a clock. Again, the metaphor/construct has taken precedence over the behavior.

Dissecting a Temporal Discrimination to Avoid Mediation

The necessity of a mediating construct like the internal clock in accounting for behavior in experiments on timing has been questioned whenever the process of establishing such behavior is considered (Dragoi, Staddon, Palmer, & Buhusi, 2003; Machado, 1997). In Chapter 7 of *The Behavior of Organisms*, Skinner (1938) outlined what an account of temporal stimulus control (an alternative to “interval timing”) from a radical behaviorist perspective might be. An animal’s behavior is usually said to show evidence of stimulus control whenever a previously reinforced response occurs in the presence of one stimulus and not another. For example, if a pigeon pecks in the presence of a red light and not a blue light, then that would meet the definition of stimulus control. However, this type stimulus change is of the abrupt type: the key light is red for a time, then the key light abruptly switches to blue after a reinforced response. Temporal stimulus control is different in that the stimulus change is gradual.

Just as in an abrupt stimulus change, (e.g., the presence or absence of a light) a gradual stimulus change (e.g., increasing intensity of a light) involves two events in the environment that have differential control of behavior—a stimulus onset and a second event, usually called the reinforcing event, that maintains responding in the presence of that stimulus. In the case of temporal stimulus control, the stimulus is displayed for a particular duration allowing for a type of stimulus continuum, much like the wavelength continuum of either light or sound. The reinforcing event is then placed at some point on the continuum of that stimulus. For example, if a key light were to slowly change from red (650 nanometers [nm]) to violet (400 nm) and grain was offered contingent upon the first peck after a green light (510 nm) appeared, then we might say that the green light had discriminative control over pecking if pecking only occurred between, say, 505 nm and 520 nm. This situation is analogous to what Ferster and Skinner (1957) describe as a “continuous clock,” with other derivations appearing later (e.g., Segal, 1962; Palya, 1993). One can conceptualize temporal stimulus control similarly. However, instead of identifying the wavelength of light at which responding is reinforced, the duration after stimulus onset at which responding is reinforced would be identified. A practical example noted by Skinner (1938) illustrates the point.

Suppose a rat is exposed to a schedule of food delivery where food is presented contingent on a response occurring after some fixed time after stimulus onset. The stimulus duration can be divided into n bins of t s, each with the bin containing reinforcement denoted as n_R . Each bin can be conceptualized as different aspects of the stimulus continuum. Because of the gradual change of the stimulus from n_x to n_R , that is, from S^A to S^D , responding may occur at times close to n_R though the majority of these responses have never directly resulted in reinforcement. That is, the difference between very early bins and n_R is certainly discriminable, which is evidenced by the postreinforcement pause often seen in responding on fixed-interval schedules. However, the difference between later bins and n_R is not as discriminable because of the gradual shift from that aspect of the stimulus not correlated with reinforcement to that aspect of the stimulus that is so-correlated. The responding this stimulus pattern engenders has been called a “break-and-run” pattern (Schneider, 1969). This

conceptualization attributes the cause of the behavior to the stimuli in the organism's environment and its history with that environment. The functional relation between behavior and environment is not said to be mediated by some physical construct, like the physiologized internal clock. To relate timing again to color discrimination, when a red stimulus is introduced into the environment and an animal responds differentially to that stimulus, a "red light discriminating mechanism" inside the organism is neither hypothesized nor made the focus of the analysis of stimulus control by the red light. Why, then, has just such a mechanism become so often the "go to" approach in the experimental analysis of temporal control?

By considering time as another stimulus property and timing as behavioral selection involving temporal stimulus control, the notion of "time" or "interval timing" can be approached without the necessity of deferring to a hypothesized timing mechanism to account for the behavior controlled by the temporal event(s) (Skinner, 1938). Instead, the behavior can be said to be differentially affected by the properties of the stimulus in relation to the organism's past history; in this case, stimulus duration with the defining terms S^A and S^D denoting when responding is less likely or more likely to occur, respectively. Indeed, there are models of timing that attempt to preserve aspects of this orientation like the LeT model proposed by Machado (1997) and various models proposed by Staddon and colleagues (e.g.,Dragoi et al., 2003; Jozefowicz, Staddon, & Cerutti, 2009). Machado's model is closely related to Killeen and Fetterman's (1988) behavioral theory of timing (BeT), but does not require a hypothesized pacemaker to produce changes in behavioral states necessary for temporal discrimination. Machado's model attempts to incorporate a learning dynamic in accounting for temporal learning, which is largely ignored by more popular timing models (e.g., SET and BeT) that offer accounts of temporal discrimination only in steady-state conditions. The LeT model provides an approach to temporal discrimination that may have satisfied radical behaviorism's call for theory construction because it supposes that "animals do not passively tell time by using central, all-purpose internal clocks; rather, they act on and interact with their environment, and in the process their behavior changes" (p. 258; Machado, 1997). That is, Machado's model attempts to understand "timing" by focusing on aspects of the organism's learning history, and it could be argued to be an account of temporally regulated behavior that is within the same dimensional system as said behavior. Likewise, Staddon's models rely on behavior–environment interactions to facilitate behavior change over time that then resemble the steady-state pattern of behavior we might call "timing." For example, the model proposed by Dragoi et al. (2003) does not assume an internal clock, but rather depends on two basic assumptions involving reinforcement-based selection of responses and the influence of reinforcement rate on arousal level of behavioral states similar to BeT (Killeen & Fetterman, 1988). Like Machado (1997), the model of Dragoi et al. (2003) attempts to account for the dynamic learning process and steady-state manifestations of temporal stimulus control. It is not the objective here to exhaustively review these models. Rather, it is to emphasize that a clockless approach to interval timing is possible, and these models represent fruitful alternatives to the dominating clock-based models. If an internal clock is to be included in the explanation of a temporal discrimination, then "we have not only overlooked much of the *process of establishing such a [pattern of behavior]*, but we emerge with an entity which has unusual properties and appears to behave anomalously" (Skinner, 1938, p. 270; emphasis added).

Conclusion: Is the Internal Clock a Manifestation of a Misguided Metaphor?

Viewing timing as the outcome of the actions of an internal clock leads, like considering other behavior as the action of strictly internal processes, to a conceptualization of the clock as an entity, an agent. In so doing, it isolates the control of behavior by temporal stimuli from environmental determinants. “Timing” is sequestered away from other behavioral processes, inviting its consideration as something requiring a unique approach previously found to be at least not optimal, and perhaps not even that useful, in the experimental analysis of other classes of stimuli of which behavior has been shown to be a function. The path to understanding the stimulus control of behavior is littered with distracting hypothetical entities that have attempted to change the direction toward entities that have faltered in keeping an understanding of environmental variables as both the target and the goal of the analysis. Just as organisms require certain physiological structures to respond to other classes of stimuli, that they require neurological mechanisms to respond to temporal stimuli has never been in dispute. What is in dispute, in this review, is the necessity of reducing the control of behavior by temporal stimuli down to either physiological or hypothetical mechanisms, like internal clocks. Approaching the internal clock in these latter two ways, and treating temporal control in ways inconsistent with the ways that other classes of stimuli are treated in the experimental analysis of behavior yields an affirmative response to the question posed in the title.

The broader implications of this review have to do with the implications and shortcomings of invoking mechanistic causation in explanations and descriptions of behavior. Some interval timing theories provide examples of how mechanistic causation can set up the conditions under which hypothetical constructs are reified and then elevated to causal status and attributed with “thingness.” It is worth repeating that these constructs initially can serve as useful heuristic tools in developing an account of any behavioral process if they suggest examination of manipulable variables that had yet to be examined. However, the transition of the construct from a heuristic to primary causal factor is a serious problem in current approaches to psychological research if they deter examination of possible influential variables. It can be argued that this reification is a manifestation of a misguided, mechanistic view of behavior. Radical behaviorism and the science that derives from that philosophy broadly benefits from variation in perspectives. This does not mean, however, that all perspectives are equally compatible with or equally useful to the science. The psychoanalyst’s couch is simply not a useful behavior-analytic tool. Science, including behavior analysis, sorts through proposed tools, and theories, through both experimental and conceptual analysis. Those that survive define utility. The present critique of the internal clock is offered as part of the process of selecting, within behavior analysis, those constructs and mechanisms—causes, in some circles—that have the greatest utility in advancing a science of behavior based on the experimental and quantitative analysis of functional relations between environmental events and behavior.

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