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Behavioural Processes

The evolution of the behavior systems framework and its connection to interbehavioral psychology ☆

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A B S T R A C T

The present article traces the development of Timberlake's behavior systems framework while noting connections between it and Kantor's interbehavioral psychology. Congruent with Timberlake's behavior systems approach, interbehaviorists assert that (a) behavior is best understood as part of a complex causal system instead of a simple linear model, (b) the study of learning and behavior analysis should consist of the study of multiple responses and the systematic observation of response forms, (c) learning involves the reorganization of a behavior system, (d) behavioral analyses should be more ecological in orientation, and (e) psychology would benefit from a set of methodologies and apparatuses broader than those normally used to study operant and Pavlovian conditioning. These connections may derive from two broad themes shared by the behavior systems framework and interbehavioral psychology: an appreciation for a systems view of behavior and the importance of ethological considerations.

1. Introduction

Timberlake's major contribution to the study of animal learning and behavior analysis may be the integration of ethological and psychological theorizing in a manner that permitted empirical testing of various aspects of this integration. He was particularly interested in a framework that melded ethological considerations with associative theories of learning. From the outset, he recognized the challenges of developing a complex causal model of animal learning and behavior: "The empirical realization of such a general model is a monumental task" (Timberlake, 1981, p. 639). The epitome of his efforts would be known as Timberlake's behavior systems framework (e.g., Timberlake, 1983, 1994, 2001; Timberlake and Lucas, 1989).

According to this framework, people and other animals' behavior is the result of integrated hierarchical-sequential systems that consist of neurological structures and processes, sensory and perceptual sensitivities and biases, and response components that are organized around important biological functions, such as procuring food, attracting mates, and escaping and avoiding predators. The *system* is the highest organizational level of behavioral control (e.g., feeding); *subsystems* that share common features is the next lower level of control (e.g., predation vs. browsing); *modes* are collections of stimulus sensitivities and

responses related to important events and to cues that announce them (e.g., general search, focused or focal search, handling/consuming); *perceptual-motor modules* refer to predispositions to respond to particular stimuli with particular actions (e.g., capturing or securing food is a stimulus event that may trigger biting); finally, specific *actions* are the lowest level (e.g., biting, chewing, swallowing). Fig. 1 shows a schematic representation of a rat's predation subsystem.

A behavior systems view posits that learning involves the reorganization of an animal's initial conditions, which consist of the effects of an animal's past experiences and its evolutionary history, to improve the fit between the operation of a behavior system and the environment. An animal's behavior is functional when the intial conditions fit the programmed or unprogrammed contingencies. When they do not fit, misbehavior results (e.g., Breland and Breland, 1961). To improve the chances of a good fit and minimize the chances of misbehavior, researchers who study learning and behavior analysis carefully engineered their apparatuses and procedures – a process Timberlake (1990) referred to as tuning.

The philosophical heritage of the behavior systems approach is "partly in functionalism and nativism" (Timberlake and Lucas, 1989, pp. 240–241) in that the "organism is assumed to begin with considerably more than a blank slate" (Timberlake and Lucas, 1989, p.

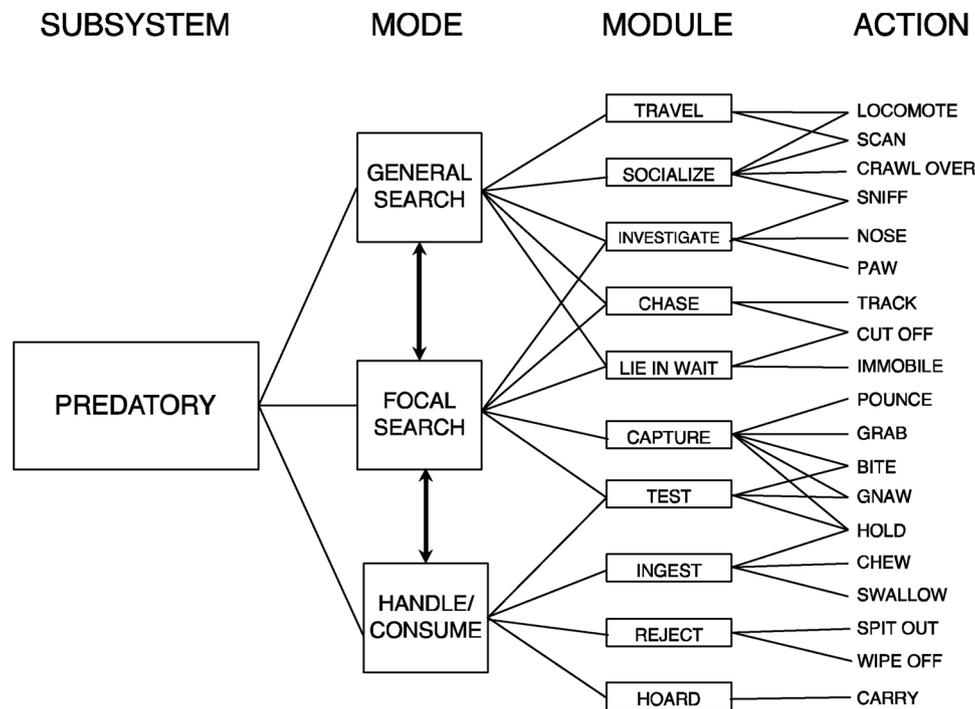SUBSYSTEM   MODE   MODULE   ACTION

Fig. 1. A schematic representation of the hierarchically-organized predation subsystem in the rat. The browsing subsystem (not shown) would have its own hierarchical organization. Adapted from Timberlake and Lucas (1989).

241). Learning consists of "changes in the existing perceptual and response structures and the motivational processes of a functioning organism" (Timberlake and Lucas, 1989, p. 241). In terms of its scientific heritage, the behavior systems approach is rooted primarily in evolutionary and organismic biology. Timberlake and Lucas acknowledged similarities between Tinbergen's (1951) hierarchical motivation model and the behavior systems view of hierarchical control. In its final form, Timberlake's behavior systems approach aligned itself mostly with classical ethology (e.g., Baerends, 1988; Lorenz, 1981; Tinbergen, 1951), early comparative psychology (e.g., Craig, 1918), and adaptive-evolutionary views of animal learning and behavior (e.g., Bolles, 1970; Garcia and Koelling, 1966; Hollis, 1982).

Although Timberlake's behavior systems framework is rooted in functionalism, nativism, and evolutionary and organismic biology, it also shares thematic affinities with interbehavioral psychology. With regard to connections between behavioral systems analyses in general (rather than the behavior systems framework in particular) and interbehavioral psychology, Ray (1995, p. 293) wrote: "Behavioral systems analysis has its conceptual and methodological roots in Kantor's interbehavioral philosophy, general systems theory, operant learning principles, and ethological assessment of behavioral patterning (Ray and Delprato, 1989)."

Interbehavioral psychology was developed by J. R. Kantor (1888–1984), a professor at Indiana University from 1920 to 1959. Kantor wrote extensively about philosophy of science and epistemology (Mountjoy, 2001). He believed that behavior could not be adequately studied as part of a simple (linear) causal model (Kantor, 1959; see also Clayton et al., 2005). As a result, interbehavioral psychology is characterized by systems thinking. Kantor (1970) represented the main components of the system – what he termed the "interbehavioral field" or "psychological event" but modern science terms the "system" (Delprato and Smith, 2009) – by the formula $PE = C(k, sf, rf, hi, st, md)$. PE represents the psychological event, which is anything an organism senses, perceives, and does in relation to a constellation of past and present stimulus conditions. C conveys that the psychological event is an integrated outcome of stimulus (sf) and response (rf) functional relations, interbehavioral history or hi (e.g., history of leverpressing;

evolutionary history), setting factors or st (e.g., time of day; presence of occasion setters), and the media of contact between environmental stimuli and the organism or md (e.g., light stimulates receptors in the eye allowing a rat to see a lever; the surface of a lever stimulates tactile receptors allowing the rat to feel the lever). The letter k symbolizes the uniqueness of every psychological event, that the same precise circumstances of a psychological event can never be repeated. In sum, "Kantor conceived of an interbehavioral field that consists of the organism and the stimulus objects in its environment reciprocally relating to each other according to psychophysical laws" (Pear, 2007, p. 138).

For interbehaviorists, learning consists of the reorganization of a behavioral system and its interrelated network of responses (Ray and Brown, 1975). Studying learning requires measuring not only changes in the frequency or magnitude of a response, but also changes in the forms of multiple responses (Morris, 1984). Because responses do not have meaning apart from the interbehavioral field, the goal of studying learning and behavior is a thorough description of the relations between responses and the other components of this field (Greenberg, 2008; Morris, 1984). Moreover, Kantor believed "that the behavioral sciences must become increasingly ecological and contextual bound in analysis" (Sharpe and Delprato, 2005, p. 347).

Kantor's belief that psychology needed to study the interrelations among multiple responses led him to criticize Pavlovian and Skinnerian approaches to the study of learning and behavior, for they relied heavily on simple linear causal models and used few preparations that consisted primarily of studying one response (operant or respondent) at a time (Kantor, 1970; see also Ray, 2011/2012Ray, /, 2012Ray, 2011/2012). Responses, even actions defined solely by the closure of a microswitch or the completion of a circuit, are not caused by the programmed contingency (i.e., independent variable). Instead, changes in responding reflect the influence of interrelated factors of which the programmed contingency is just one of them.

In what follows, we trace the development of Timberlake's behavior systems framework. Like many theories or approaches, Timberlake's framework evolved over the course of many years. The beginnings of the framework are evident in the adaptive model proposed by Timberlake and Allison (1974); the most fully-formed version of the

framework appeared in a book chapter written by Timberlake and Lucas (1989). In the process of tracing the evolution of Timberlake's behavior systems framework, we bring to light hitherto unexamined thematic affinities between it and Kantor's interbehavioral psychology.

2. A brief history of the development of the behavior systems framework

2.1. Systems thinking (1974)

Just as systems thinking is arguably the most general characteristic of interbehavioral psychology, a systems approach is the most general characteristic of the behavior systems framework. One of the earliest signs, if not the first sign, of Timberlake's systems thinking is found in a 1974 article he co-authored with Indiana University psychology professor, James Allison. In that article about response deprivation, Timberlake and Allison (1974) used an analogy of a physical system to illustrate that a reinforcer appeared to strengthen the response that preceded it (a simple causal view) because a broader system was modified by the response-reinforcer contingency (a more complex systems view). To clarify their view of the relative nature of reinforcers, Timberlake and Allison relied on the following analogy that involved Boyle's law (i.e., pressure, P, volume, V, and temperature T of a gas are related as follows: $PV = kT$, where k is a constant):

A well-known physical law states that the pressure of a gas in a fixed space [constant V] is a direct function of its temperature. Suppose, however, that the concept of temperature were not known but that researchers had cataloged "pressurizing agents" which increased the pressure of gas systems to which they were added. If all gas systems considered had similar initial temperatures, then all pressurizing agents would be transituational in their effects. However, if the gas systems differed in initial temperature, then a given pressurizing agent might increase, decrease, or have no effect on the pressure of a system to which it was added. Such phenomena can be understood and predicted only by developing the concept of temperature and the associated gas laws. (p. 147)

In other words, for fixed V and depending on the unknown value of T, applying the same pressurizing agent might increase, decrease, or have no effect on P. Similarly, according to response deprivation theory, depending on the relative amounts of the instrumental and contingent responses during a free-choice baseline condition, applying the same "reinforcing agent" might increase, decrease, or have no effect on the amount of the instrumental response.

Later in this same article, Timberlake and Allison described their systems view of reinforcement, which they termed the adaptive model of performance. Key features of this model – such as a systems view of behavior, incorporating evolutionary considerations (e.g., species-typical behavior) into traditional learning theory and behavioral analysis, an awareness that an animal's behavior in a laboratory illustrates its reaction to a constraint imposed on a preferred allocation of behavior, the causes of misbehavior, and the importance of tuning apparatuses and procedures in studies of learning – would form the basis for Timberlake's behavior systems framework:

Two major assumptions underlie the adaptive model. The first is that *instrumental performance is a result of conflict between the freely occurring behavior of the animal and the restrictions of a schedule* [emphasis added to highlight constraints theme]. The effects of a schedule *cannot be understood or predicted by considering the contingency situation alone* [emphasis added to highlight systems thinking]. … A schedule imposes sequential and quantitative constraints which typically conflict with the patterns of free behavior. (Timberlake and Allison, 1974, p. 150)

The preceding assumption aligns closely with Kantor's (1942, 1970) view that a programmed contingency does more than simply strengthen the response that produced reinforcement. For Kantor (1975, p. 140), a programmed contingency alters interrelations among behaviors, and not necessarily through strengthening:

Attacks are being made on operant-learning theory because of numerous recent researches which contravene the central notion of operantism, namely, the mighty role of reinforcement in the development and performance of behavior. Not only may a reinforcer for an operant be an unconditioned stimulus for a respondent, but great criticism is made of the general notion of reinforcement on the basis of various investigations.

Prominent among those researchers are the findings that the temporal relation between reinforcer and the response-stimulus effect is far different from the early asserted rule of contiguous association (Revusky and Garcia, 1970); then there is the phenomenon of autoshaping or sign-tracking (Brown and Jenkins, 1968; Jenkins, 1974), which nullified the importance of reinforcement entirely.

Summarizing his views of Pavlovian and operant conditioning, Kantor (1975, p. 142) wrote: "The inflation of the conditioning process into an explanatory principle … constitutes a violent travesty of scientific thinking."

Timberlake and Allison's (1974) second assumption (see below) aligns with Kantor's (1975) belief that behavioral analyses should be more ecological in orientation (see also Clayton et al., 2005).

The second major assumption of the adaptive model is that resolution of the conflict between the determinants of free behavior and the requirements of the schedule is based on the *biological equipment and capacities of the animal involved* [emphasis added to highlight evolutionary considerations]. An adaptive outcome is not necessarily most efficient (profitable) in obtaining access to the contingent response (Herrnstein, 1970). In the example above, the rat may perform responses other than bar pressing in reaction to the scheduled restriction of food. It might escape its cage, eat sawdust, nibble its pellets more efficiently, alter its metabolism of fats, bite the experimenter, or gnaw the bar. These outcomes are not equally profitable, but all are adaptive in that they follow from the *organism's functioning as a biologically evolved system* [emphasis added to again highlight systems thinking and evolutionary considerations] and *in response to the imposition of the schedule* [emphasis added to again highlight constraints theme].

Animals would be expected to show efficient performance only if their phylogenetic and ontogenetic programming provided the possibility of such a solution to the conflict imposed by the schedule [emphasis added to highlight the emphasis on the conditions that produce efficient behavior versus misbehavior]. The fact that much behavior under a schedule appears to take the form of efficient instrumental responding is probably *due primarily to a judicious selection of apparatus, animal, and procedure* [emphasis added to highlight importance of tuning], and only secondarily to the general effect of a reinforcer. (Timberlake and Allison, 1974, p. 151)

Consistent with Kantor's view of learning (see Ray and Brown, 1975), Timberlake and Allison (1974, p. 160) also suggested that learning was more about the reorganization of existing species-typical behavior or response units than the creation of new arbitrary responses: "The work on autoshaping of key pecking in pigeons and bar manipulation in rats highlights the ability of experimenters to hit upon instrumental responses that are closely related to the animal's ready-made repertoire. … Failure to use such "prepared" responses (Seligman, 1970) may result in great difficulty in learning (Bolles, 1970, 1972; Breland and Breland, 1961, 1966; Shettleworth, 1972)." Thus, according to Timberlake and Allison (1974), learning was facilitated when researchers hit upon a good fit between the apparatuses and procedures they engineered and the animal's species-typical or ready-made stimulus sensitivities and behaviors. A poor fit hindered learning.

Despite the presence of themes that would remain defining

characteristics of the behavior systems framework, key features were absent. Most notably, the integration of classical ethological views regarding the hierarchical and sequential nature of behavior was missing. As a result, Timberlake and Allison's (1974) article does not contain any references to ethologists Konrad Lorenz, Nikolaas Tinbergen, or Gerard Baerends. At this stage, the impetus for Timberlake and Allison's theorizing came from psychologists who incorporated evolution and ecology into their research: Keller and Marian Breland, Robert Bolles, Martin Seligman, and Sara Shettleworth.

2.2. "Behavior system" (1975)

It was in Timberlake and Grant's (1975) article where the term "behavior system" first appears in Timberlake's published works. The term appeared in the second to last sentence of the article: "Lorenz used this illustration to suggest that an entire behavior system was conditioned by the procedures of classical conditioning, not just an isolated reflex" (p. 692). Timberlake and Grant elaborated on what they meant by behavior system in an endnote: "A system of behavior may be viewed as a collection of species-typical sensorimotor mechanisms potentially sharing common causal factors" (p. 692).

A key idea of Timberlake's mature behavior systems framework (see Timberlake and Lucas, 1989) was introduced by Timberlake and Grant (1975). The key idea was that an entire behavior system rather than a specific conditioned response (CR) gets conditioned during Pavlovian conditioning. (Timberlake would later say that modes rather than whole systems become conditioned during Pavlovian conditioning; see Timberlake, 1994, 2001). The responses that are evoked by a conditioned stimulus (CS) depend on the nature of the CS and other supporting features of the environment. For example, for a hungry rat, a diffuse tone that predicts food may elicit swimming toward the location of food if the conditioning environment consists of a pool filled with water but elicits scurrying to the food site if the pool is empty. What gets conditioned to the tone is a set of responses (e.g., approach to the food site) rather than a specific response (e.g., swimming vs. scurrying). Timberlake and Grant (1975) wrote the following about this aspect of Pavlovian conditioning: "As an alternative to stimulus substitution, we offer the hypothesis that auto-shaped behavior reflects the conditioning of a system of species-typical behaviors commonly related to the reward. The form of behavior in the presence of the predictive stimulus will depend on which behaviors in the conditioned system are elicited and supported by the predictive stimulus" (p. 692).

Timberlake and Grant's view was an alternative to stimulus substitution accounts of conditioned responding. In support of their view, they showed that rats, which are social feeders, approached and interacted socially with a live rat that predicted food. The rat CS evoked social responses, not eating the CS, which is the response predicted by stimulus substitution. Timberlake and Grant's study highlighted the importance of an animal's biology to the form of conditioned responding. Interbehaviorists also promote the incorporation of biological considerations into psychological theorizing: "Biological influences upon psychological behavior constitute the actualization of potentialities resident in the morphology and ecological evolution of organisms. These factors when actualized in concrete behavior participate in the behavioral situation as abilities and limitations of action" (Kantor, 1975, p. 143).

Despite this like-mindedness with interbehavioral psychology, the key references in Timberlake and Grant's article were to the works of comparative psychologists (Jerry Hogan and Bennett Galef) and ethologists (Gerard Baerands and Konrad Lorenz). Still absent was any explicit reference to the work of ethologist Nikolaas Tinbergen, the hierarchical-sequential organization of behavior systems, and the conditioning of specific features of a behavior system rather than a whole system.

2.3. The organization of behavior systems: a preview (1981)

In 1981, Timberlake wrote a commentary for a *Behavioral and Brain Sciences (BBS)* target article that Gallistel (1981) wrote about the organization of action. It was here where Timberlake (1981) first referred to the organization of behavior as hierarchical and speculated about the characteristics of the hierarchical organization: "shaped like hourglasses, diamonds, or even upside-down pyramids" and "levels in a hierarchy may not be fixed but may actually reverse under different circumstances" (p. 638). Echoing interbehaviorist views that behavior was best understood as part of a complex causal system (e.g., Richling et al., 2017), Timberlake wrote that "we must treat behavior as an entity of complex causation and control" (p. 638). Timberlake also referred to what would be the first major description of his behavior systems framework. Citing a chapter that he had written but which would not be published for two years, Timberlake gave readers a preview of his model:

> I recently suggested such a model [of the structures an animal brings to a learning situation] to account for the behavior of two rodent species toward conspecifics that predicted food (Timberlake, 1981). Within this model, low-level sensorimotor units (such as reflexes, taxes, and oscillators) are combined into larger units of perceptual-motor organization called modules. Each module consists of responses that show statistical sequential/temporal relations and can be elicited, controlled, and terminated by particular stimuli. The modules are organized in a loosely hierarchical fashion into systems serving a common function (such as the feeding system). Potentiation consists of input at the system level, and depotentiation depends on the nature and temporal relation of controlling stimuli. (p. 639)

As part of this preview, Timberlake summarized what learning does and how it occurs:

> Learning is presumed to occur within these systems in the form of modification of the frequency, order, timing, integration, and elicitation of subunits, modules, and systems. Further, depending on the level and function, learning may occur as the result of response feedback, stimulus-response pairing, motor repetition, or stimulus presentation. (p. 639)

Finally, Timberlake noted the difficulty of testing a complex causal model of learning and behavior: "The empirical realization of such a general model is a monumental task. It may well be no more than a heuristic guide to other models" (p. 639). Similar sentiments have been expressed about interbehavioral psychology. That is, regardless of the correctness of interbehavioral psychology, its complexity makes empirical testing and interpretation of the results challenging (see Marr, 1984; Schoenfeld, 1969).

2.4. Behavior systems and learning (1983)

The first comprehensive description of the behavior systems framework was published in a 1983 chapter where Timberlake (1983) discussed the distinctions, divisions, and relative strengths and weakness of ecological and arbitrary approaches to the study of learning and behavior analysis. Tinbergen's (1951) contributions to the behavior systems framework were evident when Timberlake (1983) argued that an animal's behavior is "organized into systems of processes that serve particular survival functions by relating stimuli, responses, and internal states" (p. 183), and that the organization of most behavior systems was "semi-hierarchical" (p. 184).

This chapter is also noteworthy for its continued embrace of ethological concepts and how these could help psychologists understand phenomena such as sign-tracking, autoshaping, and misbehavior. The added discussion of Tinbergen's (1951) hierarchically-organized model of motivational states strengthened the connection between the
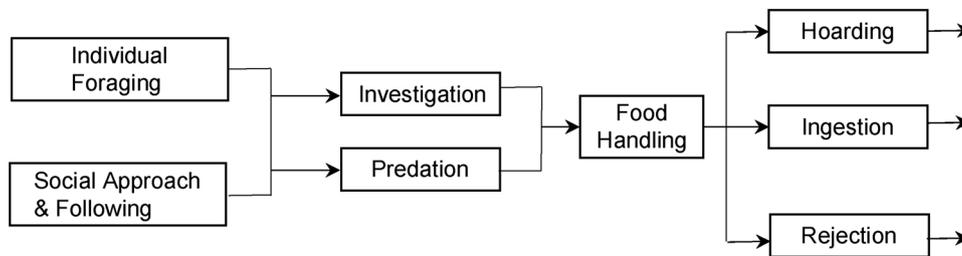
Fig. 2. A schematic representation of some components of the behavioral feeding system in the rat. Redrawn from Timberlake (1983).

behavior systems framework and classical ethology. Related to Tinbergen's model, Timberlake (1983) proposed for the first time a schematic representation of the feeding system of a rat (see Fig. 2), a schematic that would become more complex and complete in future publications of his behavior systems framework (see Fig. 1).

Timberlake described the behavior systems model as consisting of a system (e.g., feeding, mating, parenting) and perceptual-motor modules: "Each system is composed of smaller organized units of perceptual-motor organization which I will call modules. Each perceptual-motor module consists of responses that show a probabilistic sequential and/or temporal relation, and are probabilistically elicited, controlled, and terminated by particular stimuli" (Timberlake, 1983, p. 184). Moreover, the modules are "organized in a semi-hierarchical fashion such that some modules normally precede or follow other modules. Most modules are vertically integrated, involving skeletal, neuromuscular, hormonal, and sensory processes" (p. 184). Timberlake listed the modules comprising the rat's feeding system: individual foraging, social-approach, investigation, predation, food handling, hoarding, ingestion, and rejection.

Still absent from Timberlake's 1983 version of his behavior systems framework, however, was any mention of modes – what he would later refer to as the general search, focal search, and handling/consuming modes (see Timberlake and Lucas, 1989). Although subsystems (e.g., predation vs. browsing) also were absent in this version of the behavior systems model, the roots of what would become the subsystem level were present in that Timberlake identified investigation and predation as separate modules that led sequentially to a food handling module. In short, the pieces of what would become the complete version of the behavior systems framework that was published in 1989 were present in the 1983 chapter. What was not yet well developed in 1983 was how the different pieces fit together; that is, their organization.

Independently of Timberlake's work, interbehaviorists had been writing about, studying, and producing their own schematics of hierarchically-organized behavior systems. Writing about their systems view of behavior, Ray and Brown (1975, p. 473) stated: "the simple motor behaviors of the laboratory rat exist as an interdependent *system of behaviors*. When an intervention was performed on one of the behaviors … the organization of the system as a whole was also changed. These changes in organization suggest that the system is sequentially organized with mutually interdependent components." Writing about the same topic, Ray et al. (1977, p. 678) added: "interbehavioral networks involve the interfacing of hierarchically arranged environmental

systems and homeostatically balanced organismic systems." Fig. 3 shows how Ray and Brown (1975) conceptualized the organization of rats' behavior during an operant conditioning task. Although hierarchical in its organization, Ray and Brown's conceptualization of a rat's behavior lacks an obvious reason for its structure. In contrast, Timberlake's (1983) modules – preorganized stimulus sensitivities and response tendencies – provide the pillars for his view of the organization of the rat's feeding system.

2.5. Search modes: a preview (1988)

The first mention of modes appears in Timberlake's (1988) commentary of a *BBS* target article about self-control that was written by Logue (1988). As he did in his *BBS* commentary seven years prior (see Timberlake, 1981), Timberlake previewed what would become his most complete articulation of the behavior systems framework: "two partially overlapping motivational states or modes, general and focal search" (p. 694) controlled perceptual-motor modules – packets of stimulus sensitivities and motor programs. He explained that "general search refers to exploratory and systematic search behaviors related to increasing the likelihood of locating and capturing food. Focal search refers to behaviors related to the actual capture and handling of food" (Timberlake, 1988, p. 694). A more complete description of these two modes and the addition of a third mode (handling/consuming) would be published a year later.

2.6. The behavior systems framework (1989)

In a chapter co-authored with Gary Lucas, Timberlake added to his behavior systems framework by expanding and elaborating upon the example of the hierarchical feeding system of a rat. It was in this chapter that the schematic of a rat's predation subsystem was presented (see Fig. 1). This schematic illustrated that the rat's predation subsystem consisted of three search modes, each with associated stimulus sensitivities and responses. Timberlake and Lucas (1989) explained that, for a hungry animal, the presence of food engaged an organized sequence of search modes: general search, focal search, and handling/consuming. Focal search was further subdivided into pre- and post-food focal search. Similar hierarchically-organized systems existed for other animals, for other appetitive goals (e.g., obtaining food, water, mates), and for escaping or avoiding aversive events (e.g., avoiding predators or inclement weather).
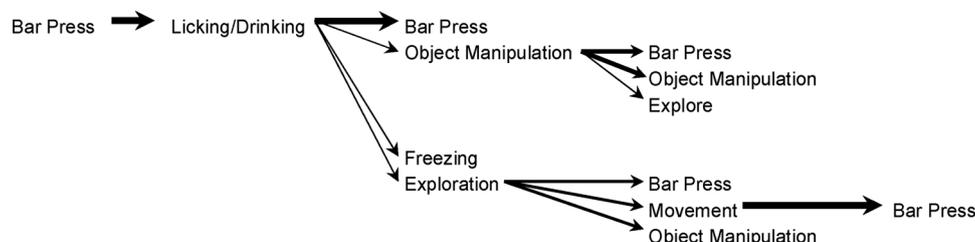

Fig. 3. An example of a hierarchical organization of rats' responses in the presence of an S + where pressing a lever results in water reinforcement. The width of the connecting arrows conveys the probability of each sequence (thicker arrows indicate higher probabilities). Adapted from Ray and Brown (1975).

In their example, Timberlake and Lucas described how rats forage for food by starting in a general search mode, characterized by attention to general contexts and cues related to food but not imminent food. When a rat finds better predictors of food, the focal search mode is engaged. The focal search mode is characterized by stimulus sensitivities and responses related to an imminent encounter with better predictors of food or food itself. Once food is located and contacted, it engages a handling/consuming mode. Handling/consuming responses consist of biting, chewing, and eating food. Following ingestion, the rat re-enters the focal search mode that again activates stimulus sensitivities and responses related to an imminent encounter with better predictors of food or food itself. If more food is found, the rat returns to a handling/consuming mode. If more food is not found quickly, the passage of time and other cues that food is not imminent begins to engage the general search mode. This sequencing through the search modes continues until the rat is satiated or a bout of foraging ends for some other reason (e.g., the rat has to evade a predator).

In Timberlake and Lucas's (1989) chapter, predictions about response form during Pavlovian conditioning, which first appeared in Timberlake and Grant (1975), were made more explicit. Timberlake and Lucas (1989) reasoned that there are optimal CS durations and optimal CS-US intervals for different search modes. Thus, the relative strength and expression of a mode depends on the nature of the CS and its spatiotemporal proximity to the US. A CS that is presented temporally close to a food US (e.g., a brief CS and a short CS-US interval) should come to condition a focal search mode and appropriate responses (e.g., feeder-directed behavior), whereas a CS presented temporally distant from a food US (e.g., a long-duration CS whose onset precedes the US by many seconds) should come to condition responses correlated with an earlier search mode (e.g., locomotion and a tendency to chase moving stimuli). Which responses are evoked by a CS is probabilistic and depends on how well the characteristics of the CS, US, and other aspects of the experimental environment support one response over another.

Timberlake and Lucas reiterated that learning consists of the reorganization of an animal's initial conditions so as to improve the fit between the operation of a behavior system and the environment. As such, Pavlovian and operant conditioning were two procedures for modifying the fit between a behavior system and the environment, not two types learning (e.g., Kimble, 1961). This view is shared by Kantor and other interbehaviorists. For example, Ray and Brown (1975, p. 473) wrote, "a definition of learning as a 'reorganization of interbehavioral events (Kantor, 1959)' ought to be considered as a possible basic framework for a new conceptualization of behavior change. A definition that does not take into account the systems properties of behavior cannot provide an adequate base for theory construction." On the distinction between Pavlovian and operant conditioning, Ray and Brown (1976, p.21) wrote that "learning procedures actually represent a parametric continuum of related procedures comprised of the specification of … 'base behaviors' for *probabilistic* stimulus deliveries. These stimulus deliveries then determine the nature of many alternations in behavioral flow dynamics…."

The idea of apparatus and procedure tuning figured prominently in Timberlake and Lucas's (1989) behavior system framework. Tuning is the process of modifying apparatuses and procedures to improve the chances of a good fit between what an animal brings to an experiment (i.e., the animal's initial conditions) and the programmed and unprogrammed contingencies so as to reduce the chances of misbehavior. For Timberlake and Lucas, tuning was evidence for their systems view of learning and behavior: "tuning indicates the existence of coherent determinants of learned behavior that are not addressed in traditional theory" (p. 240). In relation to tuning, Timberlake and Lucas (as Kantor had many years earlier) advocated for a broader set of methodologies than those normally used to study operant and Pavlovian conditioning.

In a section Timberlake and Lucas (1989) entitled *Philosophical and Scientific Heritage*, they discussed the heritage of the behavior systems framework: classical ethology, comparative psychology, and adaptive-evolutionary approaches to the study of learning. But as we have tried to illustrate, their behavior systems framework also includes thematic affinities with interbehavioral psychology. Interbehaviorists believe that simple linear causal models are insufficient for a science of behavior, something akin to trying to understand the cause of weather with a simple linear model. Interbehaviorists believe that behavior should be studied as part of a complex causal system (Morris et al., 1982; Richling et al., 2017). Proponents of a behavior systems approach are like-minded (see Timberlake, 1993a, 2004). Interbehaviorists believe also that the study of learning and behavior analysis should encompass multiple responses and the systematic observation of response forms (Richling et al., 2017). Proponents of a behavior systems approach think similarly (see Timberlake and Silva, 1994). Interbehaviorists think that learning involves the reorganization of the structure of a behavior system. Proponents of a behavior systems approach agree (see Timberlake and Lucas, 1989).

2.7. The behavior systems framework and interbehavioral psychology

Given that Timberlake's behavior systems framework shares some connections with Kantor's interbehavioral psychology, why were the thematic affinities between these two approaches not noted previously? Any answer would be mere speculation. One thing is clear: no major writings of psychologists identified with the constraints on learning movement have cited a connection between their views and those of Kantor or interbehavioral psychology (see Bolles, 1970; Breland and Breland, 1961; Domjan, 1983, 2005; Hollis, 1982, 1997; Rozin and Schull, 1988; Seligman, 1970; Shettleworth, 1972, 2010). And although some interbehaviorists have acknowledged connections between their views and the biological constraints on learning views, they did not see or at least acknowledge connections to Timberlake's behavior systems framework (e.g., Ray and Brown, 1975; Ray and Delprato, 1989) or did so only superficially (e.g., Delprato, 1986). An article entitled *Behavioral field systems analysis: History and scientific relatives* (Delprato, 1992) – although about behavioral systems analysis and its connections to "scientific relatives" – overlooked connections to Timberlake's behavior systems. It seems that the constraints on learning approaches, of which Timberlake's behavior systems framework is a subset, and interbehavioral psychology simply failed to see or appreciate the thematic affinities they shared. To this fact, we add a speculative note. Timberlake attempted to ground animal learning and behavior analysis in solid biological/ethological principles. He wanted to reconcile Functionalism and Associationism and thereby unravel the intricacies of learning; Kantor wanted to develop a philosophical framework for understanding human behavior (Delprato, 2003). Kantor argued for the importance of identifying and examining unacknowledged fundamental assumptions in psychology (Delprato, 2003). Timberlake did the same, but his focus was more targeted (some would say, narrower): to examine fundamental assumptions in traditional conceptualizations of learning (see Timberlake, 1993a, 1994). In short, Timberlake's focus was simply different from Kantor's focus.

Because Kantor was primarily a philosopher of science rather than an investigator (Killeen, 1988), he "set things up in so abstract and general a fashion, with his ideas being so nonconcrete and nonspecific, that it was virtually impossible to falsify them" (Greenberg, 2008, p. 673). As a result, Kantor's views generated few empirical studies. Writing about the dearth of research spawned by Kantor's views, Verplanck (1995) – a self-acknowledged Kantorian and interbehaviorist – wrote: "It was all but impossible for students to complete dissertation requirements under Kantor's direction. Able students of Kantor had to complete their dissertations under the direction of others. [Kantor had] no published experimental research of his own, nor dissertation students publishing research" (p. 10). Countering these views with assertions that, for interbehaviorists, hypotheses are not something to test but guides to the identification of variables and the development of

Evolution of the Behavior Systems Framework

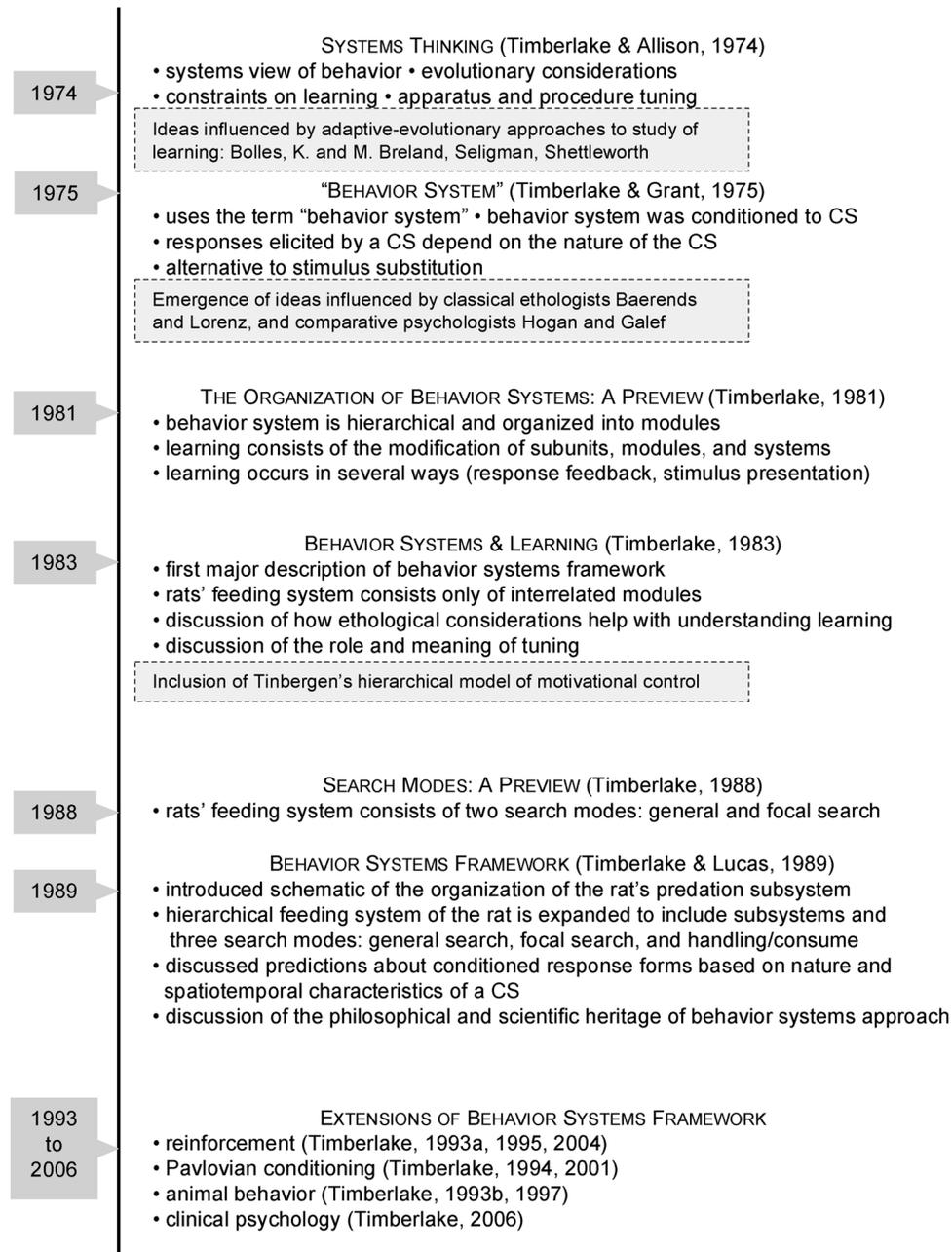|	
1974	SYSTEMS THINKING (Timberlake & Allison, 1974) • systems view of behavior • evolutionary considerations • constraints on learning • apparatus and procedure tuning
	Ideas influenced by adaptive-evolutionary approaches to study of learning: Bolles, K. and M. Breland, Seligman, Shettleworth
1975	"BEHAVIOR SYSTEM" (Timberlake & Grant, 1975) • uses the term "behavior system" • behavior system was conditioned to CS • responses elicited by a CS depend on the nature of the CS • alternative to stimulus substitution
	Emergence of ideas influenced by classical ethologists Baerends and Lorenz, and comparative psychologists Hogan and Galef
1981	THE ORGANIZATION OF BEHAVIOR SYSTEMS: A PREVIEW (Timberlake, 1981) • behavior system is hierarchical and organized into modules • learning consists of the modification of subunits, modules, and systems • learning occurs in several ways (response feedback, stimulus presentation)
1983	BEHAVIOR SYSTEMS & LEARNING (Timberlake, 1983) • first major description of behavior systems framework • rats' feeding system consists only of interrelated modules • discussion of how ethological considerations help with understanding learning • discussion of the role and meaning of tuning
	Inclusion of Tinbergen's hierarchical model of motivational control
1988	SEARCH MODES: A PREVIEW (Timberlake, 1988) • rats' feeding system consists of two search modes: general and focal search
1989	BEHAVIOR SYSTEMS FRAMEWORK (Timberlake & Lucas, 1989) • introduced schematic of the organization of the rat's predation subsystem • hierarchical feeding system of the rat is expanded to include subsystems and three search modes: general search, focal search, and handling/consume • discussed predictions about conditioned response forms based on nature and spatiotemporal characteristics of a CS • discussion of the philosophical and scientific heritage of behavior systems approach
1993 to 2006	EXTENSIONS OF BEHAVIOR SYSTEMS FRAMEWORK • reinforcement (Timberlake, 1993a, 1995, 2004) • Pavlovian conditioning (Timberlake, 1994, 2001) • animal behavior (Timberlake, 1993b, 1997) • clinical psychology (Timberlake, 2006)

Fig. 4. Timeline (not drawn to scale) of key features and ideas in the behavior systems framework.

procedures (Richling et al., 2017), description and explanation are not sharply differentiated in interbehavioral psychology (Hayes and Fryling, 2009), and science is about discovering relations among factors rather than testing ideas, does not change the widespread belief that Kantor's views were not readily amenable to empirical research (see Morris et al., 1982).

Moreover, fusing description and explanation does not preclude empirical testing. Remarking on the relationship between description, prediction, and testing, Timberlake (1993a, p. 119) wrote, "Although the complexity of a behavior system may appear to make it a better candidate for after-the-fact explanation than for a priori prediction, once a system is constructed from observations and previous experiments it is actually quite a powerful prediction device." With regard to the critical test tradition in psychology, he acknowledged that while there is great value to the time-honored tradition of a scientific shoot-out between hypotheses, he wanted "to see a new tradition of critical tests that identified potential commonalities and complementary qualities as well as important differences" (Timberlake, 1994, p. 414).

In this regard, the two Indiana University professors, Kantor and Timberlake, are quite dissimilar. Many of Timberlake's major writings about the behavior systems approach contain testable ideas and predictions, such as when he listed seven hypotheses based on his behavior systems model (see Timberlake, 1983). Timberlake developed a myriad of apparatuses and procedures for testing the behavior systems framework. For example, in addition to traditional straight-alley and radial-arm mazes, Timberlake placed radial-arm mazes on floors to test whether rats would follow the paths (arms) or venture off the paths and more efficiently traverse the maze (e.g., Roche and Timberlake, 1998). In addition to presenting rats with lights and tones, Timberlake designed an apparatus that presented these animals with a rat that served

as a CS (Timberlake and Grant, 1975) and with rolling ball-bearings that served as CSs or probes of what these animals had learned (e.g., Timberlake et al., 1982). Together with Gary Lucas, Timberlake conducted what may be the definitive study of so-called superstition in the pigeon (Timberlake and Lucas, 1985). What they showed was that rather than idiosyncratic adventitiously reinforced responses, pigeons show remarkable consistencies in response forms – some of which are observed in young squab and foraging pigeons – related to the physical characteristics of the experimental chamber (such as whether the food aperture was in a wall or in a floor). In short, Timberlake's behavior systems framework generated a rich and prolific interdisciplinary research program that has produced dozens of published empirical studies.

Despite its success stimulating empirical research and providing a framework for understanding many aspects of learning, the creativity, conceptual breadth, and complexity of Timberlake's behavior systems framework – like that of Kantor's interbehavioral psychology – comes with costs. Psychologists do not have the epistemic means to define operationally and analytically (see Machado et al., 2000) the main constructs of the behavior systems framework. Perhaps as a consequence, they do not yet have the methodological tools to test a systems-oriented view of behavior (but see Silva and Timberlake, 1998; Timberlake and Lucas, 1991). Addressing criticism that the behavior systems approach is too complex, Timberlake (1994, p. 415) stated that the apparent complexity arises because of "the failure of the traditional associative account to acknowledge and make clear the full set of assumptions and requirements necessary for its testing and application. … The complexity of the behavior systems approach lies at the level of establishing the characteristics of the system. But that is where it should be."

Notwithstanding these costs, perhaps one of the most valuable aspects of Timberlake's behavior systems approach and Kantor's interbehavioral psychology is that they caution us against generalizing our findings and interpretations hastily. That is, given the conditions under which experiments in learning and behavior analysis are conceived and run, psychologists should be more careful about how they interpret the generality of their findings.

2.8. Postscript: the behavior systems framework since 1989

A timeline of the behavior systems framework is shown in Fig. 4. Although subsequent articles and chapters about the behavior systems approach did not change its major tenets, Timberlake continued to refine his framework. For example, he modified the behavior systems framework to illustrate how the characteristics of different stimuli serve as inputs for different modules, which are differentially sensitive to different stimuli, and how these modules activate different specific actions (see Timberlake, 1994). He also continued to use the behavior systems framework as a nexus for integration with different areas of psychology and animal behavior. Timberlake wrote about the relation of the behavior systems framework to Pavlovian conditioning (see Timberlake, 1994, 2001), reinforcement and operant contingencies (see Timberlake, 1993a, 1995, 2004), animal behavior in field, laboratory, and applied settings (see Timberlake, 1993b, 1997), and clinical psychology (see Timberlake, 2006).

References

Baerends, G.P., 1988. Ethology. In: Atkinson, R.C., Herrnstein, R.J., Lindzey, G., Luce, R.D. (Eds.), Stevens' Handbook of Experimental Psychology: vol.2. Learning and Cognition, 2nd ed. Wiley, New York, pp. 765–830.

Bolles, R.C., 1970. Species-specific defense reactions and avoidance learning. Psychol. Rev. 77, 32–48. https://doi.org/10.1037/h0028589.

Bolles, R.C., 1972. Reinforcement, expectancy, and learning. Psychol. Rev. 79, 394–409. https://doi.org/10.1037/h0033120.

Breland, K., Breland, M., 1961. The misbehavior of organisms. Am. Psychol. 16, 681–684. https://doi.org/10.1037/h0040090.

Breland, K., Breland, M., 1966. Animal Behavior. Macmillan, New York.

Brown, P.L., Jenkins, H.M., 1968. Auto-shaping of the pigeon's key-peck. J. Exp. Anal. Behav. 11, 1–8. https://doi.org/10.1901/jeab.1968.11-1.

Clayton, M.C., Hayes, L.J., Swain, M.A., 2005. The nature and value of scientific systems building: The case for interbehaviorism. Psychol. Rec. 55, 335–359. https://doi.org/10.1007/BF03395515.

Craig, W., 1918. Appetites and aversions as constituents of instincts. Biol. Bull. Marine Biol. Lab. (Woods Hole, MA) 34, 91–107.

Delprato, D.J., 1986. Response patterns. In: Reese, H.W., Parrott, L.J. (Eds.), Behavior Science: Philosophical, Methodological, and Empirical Advances. Erlbaum, Hillsdale, NJ, pp. 61–113.

Delprato, D.J., 1992. Behavioral field systems analysis: history and scientific relatives. J. Teach. Phys. Educ. 12, 3–8.

Delprato, D.J., 2003. J. R. Kantor's interbehavioral psychology and humanism. Psychol. Rec. 53, 3–14.

Delprato, D.J., Smith, N.W., 2009. Sketch of J. R. Kantor's psychological interbehavioral field theory. Psychol. Rec. 59, 671–678. https://doi.org/10.1007/BF03395686.

Domjan, M., 1983. Biological constraints on instrumental and classical conditioning: implications for general process theory. In: In: Bower, G.H. (Ed.), The Psychology of Learning and Motivation, vol. 17. Academic Press, New York, pp. 215–277.

Domjan, M., 2005. Pavlovian conditioning: A functional perspective. Annu. Rev. Psychol. 56, 179–206. https://doi.org/10.1146/annurev.psych.55.090902.141409.

Gallistel, C.R., 1981. Précis of Gallistel's The organization of action: A new synthesis. Behav. Brain Sci. 4, 609–650. https://doi.org/10.1017/S0140525X00000480.

Garcia, J., Koelling, R.A., 1966. Relation of cue to consequence in aversion learning. Psychon. Sci. 4, 123–124. https://doi.org/10.3758/BF03342209.

Greenberg, G., 2008. Psychology from the standpoint of an interbehaviorist: A review of "Modern perspectives on J. R. Kantor and interbehaviorism. Psychol. Rec. 58, 665–676. https://doi.org/10.1007/BF03395643.

Hayes, L.J., Fryling, M.J., 2009. Toward an interdisciplinary science of culture. Psychol. Rec. 59, 679–700. https://doi.org/10.1007/BF03395687.

Herrnstein, R.J., 1970. On the law of effect. J. Exp. Anal. Behav. 13, 243–266. https://doi.org/10.1901/jeab.1970.13-243.

Hollis, K.L., 1982. Pavlovian conditioning of signal-centered action patterns and autonomic behavior: A biological analysis of function. Adv. Study Behav. 12, 1–64. https://doi.org/10.1016/S0065-3454(08)60045-5.

Hollis, K.L., 1997. Contemporary research on Pavlovian conditioning: A "new" functional analysis. Am. Psychol. 52, 956–965. https://doi.org/10.1037/0003-066X.52.9.956.

Jenkins, H.M., 1974. Behavior Theory Today: a Return to Fundamentals. First Mexican Conference on the Analysis of Behavior.   Xalapa, Veracruz. .

Kantor, J.R., 1942. Preface to interbehavioral psychology. Psychol. Rec. 5, 173–193.

Kantor, J.R., 1959. Interbehavioral Psychology. Principia Press, Bloomington, IN.

Kantor, J.R., 1970. An analysis of the experimental analysis of behavior (TEAB). J. Exp. Anal. Behav. 13, 101–108. https://doi.org/10.1901/jeab.1970.13-101.

Kantor, J.R., 1975. Antibehaviorism: Counterrevolution or semantic confusion? Psychol. Rec. 25, 139–145. https://doi.org/10.1007/BF03394297.

Killeen, P.R., 1988. The reflex reserve. J. Exp. Anal. Behav. 50, 319–331. https://doi.org/10.1901/jeab.1988.50-319.

Kimble, G.A., 1961. Hilgard and Marquis' Conditioning and Learning. Appleton-Century-Crofts, New York.

Logue, A.W., 1988. Research on self-control: an integrative framework. Behav. Brain Sci. 11, 665–679. https://doi.org/10.1017/S0140525X00053978.

Lorenz, K., 1981. The Foundations of Ethology. Springer-Verlag, New York.

Machado, A., Lourenço, O., Silva, F., 2000. Facts, concepts, and theories: the shape of psychology's epistemic triangle. Behav. Philos. 28, 1–40.

Marr, M.J., 1984. Some reflections on Kantor's (1970) "An Analysis of the Experimental Analysis of Behavior (TEAB)". Behav. Anal. 7, 189–196. https://doi.org/10.1007/BF03391902.

Morris, E.K., 1984. Interbehavioral psychology and radical behaviorism: Some similarities and differences. Behav. Anal. 7, 197–204. https://doi.org/10.1007/BF03391903.

Morris, E.K., Higgins, S.T., Bickel, W.K., 1982. The influence of Kantor's interbehavioral psychology on behavior analysis. Behav. Anal. 5, 158–173. https://doi.org/10.1007/BF03392384.

Mountjoy, P.T., 2001. Jacob Robert Kantor (1888-1984). Pioneer in the development of naturalistic foundations for behavior therapy. In: O'Donohue, W.T., Henderson, D.A., Hayes, S.C., Fisher, J.E., Hayes, L.J. (Eds.), A History of the Behavioral Therapies: Founders' Personal Histories. Context Press, Reno, NV, pp. 75–103.

Pear, J.J., 2007. A Historical and Contemporary Look at Psychological Systems. Erlbaum, Mahwah, NJ.

Ray, R.D., 1995. A behavior systems approach to adaptive computerized instructional design. Behav. Res. Methods Instrum. Comput. 27, 293–296. https://doi.org/10.3758/BF03204749.

Ray, R. D. CyberRat, interbehavioral systems analysis, and a "Turing Test" trilogy, Behav. Philos. 39/40, 2011/2012, 203-300.

Ray, R.D., Brown, D.A., 1975. A systems approach to behavior. Psychol. Rec. 25, 459–478. https://doi.org/10.1007/BF0339.

Ray, R.D., Brown, D.A., 1976. The behavioral specificity of stimulation: a systems approach to procedural distinctions of classical and instrumental conditioning. Pavlov. J. Biol. Sci. 11, 3–23. https://doi.org/10.1007/BF03000534.

Ray, R.D., Delprato, D.J., 1989. Behavioral systems analysis: methodological strategies and tactics. Behav. Sci. 34, 81–127. https://doi.org/10.1002/bs.3830340202.

Ray, R.D., Upson, J.D., Henderson, B.J., 1977. A systems approach to behavior III: organismic pace and complexity in time-space fields. Psychol. Rec. 27, 649–682. https://doi.org/10.1007/BF03394490.

Revusky, S., Garcia, J., 1970. Learned associations over long delays. In: In: Bower, G.H. (Ed.), The Psychology of Learning and Motivation: Advances in Research and Theory, vol. 4. Academic Press, New York, NY, pp. 1–84.

Richling, S.M., Luke, M.M., Hayes, L.J., Legaspi, D.N., 2017. Interbehavioral research: A commentary on the investigative and interpretive domains. Conductual 5, 5–16.

Roche, J.P., Timberlake, W., 1998. The influence of artificial paths and landmarks on the foraging behavior of Norway rats (*Rattus norvegicus*). Anim. Learn. Behav. 26, 76–84. https://doi.org/10.3758/BF03199163.

Rozin, P., Schull, J., 1988. The adaptive-evolutionary point of view in experimental psychology. In: Atkinson, R.C., Herrnstein, R.J., Lindzey, G., Luce, R.D. (Eds.), Stevens' Handbook of Experimental Psychology: Vol.1. *Perception and Motivation*, 2nd ed. Wiley, New York, NY, pp. 503–546.

Schoenfeld, W.N., 1969. J. R. Kantor's *Objective psychology of grammar* and *Psychology and logic*: a retrospective appreciation. J. Exp. Anal. Behav. 12, 329–347. https://doi.org/10.1901/jeab.1969.12-329.

Seligman, M.E.P., 1970. On the generality of the laws of learning. Psychol. Rev. 77, 406–418. https://doi.org/10.1037/h0029790.

Sharpe, T.L., Delprato, D.J., 2005. J. R. Kantor's interbehaviorism: Major contributions to the field. In: Hersen, M., Rosqvist, J. (Eds.), Encyclopedia of Behavior Modification and Cognitive Behavior Therapy: vol. 1. Adult Clinical Applications. Sage Publications, Thousand Oaks, CA, pp. 346–353.

Shettleworth, S.J., 1972. Constraints on learning. In: Lehrman, D.S., Hinde, R.A., Shaw, E. (Eds.), Advances in the Study of Behavior Vol. 4. Academic Press, New York, pp. 1–68.

Shettleworth, S.J., 2010. *Cognition, Evolution, and Behavior*, 2nd ed. Oxford., New York.

Silva, K.M., Timberlake, W., 1998. A behavior systems view of responding to probe stimuli during an interfood clock. Anim. Learn. Behav. 26, 313–325. https://doi.org/10.3758/BF03199224.

Timberlake, W., 1981. The education of behaviorism and the nature of learning. Behav. Brain Sci. 4, 638–639. https://doi.org/10.1017/S0140525X00000728.

Timberlake, W., 1983. The functional organization of appetitive behavior: behavior systems and learning. In: Zeiler, M.D., Harzem, P. (Eds.), *Advances in the Analysis of Behaviour*: vol. 3. Biological Factors in Learning. Wiley, Chichester, England, pp. 177–221.

Timberlake, W., 1988. Evolution, behavior systems, and "self-control": the fit between organism and test environment. Behav. Brain Sci. 11, 694–695. https://doi.org/10.1017/S0140525X00054157.

Timberlake, W., 1990. Natural learning in laboratory paradigms. In: Dewsbury, D.A. (Ed.), Contemporary Issues in Comparative Psychology. Sinauer Associates, Sunderland, MA, pp. 31–54.

Timberlake, W., 1993a. Behavior systems and reinforcement: an integrative approach. J. Exp. Anal. Behav. 60, 105–128. https://doi.org/10.1901/jeab.1993.60-105.

Timberlake, W., 1993b. Animal behavior: a continuing synthesis. Annu. Rev. Psychol. 44, 675–708. https://doi.org/10.1146/annurev.ps.44.020193.003331.

Timberlake, W., 1994. Behavior systems, associationism, and Pavlovian conditioning.

Psychon. Bull. Rev. 1, 405–420. https://doi.org/10.3758/BF03210945.

Timberlake, W., 1995. Reconceptualizing reinforcement: a causal system approach to reinforcement and behavior change. In: O'Donohue, W.T., Krasner, L. (Eds.), Theories in Behavior Therapy. APA Books, Washington, DC, pp. 59–96.

Timberlake, W., 1997. An animal-centered, causal-system approach to the understanding and control of behavior. Appl. Anim. Behav. Sci. 53, 107–129. https://doi.org/10.1016/S0168-1591(96)01154-9.

Timberlake, W., 2001. Motivational modes in behavior systems. In: Mowrer, R.R., Klein, S.B. (Eds.), Handbook of Contemporary Learning Theories. Erlbaum, Hillsdale NJ, pp. 155–209.

Timberlake, W., 2004. Is the operant contingency enough for a science of behavior? Behavior and Philosophy 32, 197–229.

Timberlake, W., 2006. Evolution-based learning mechanisms can contribute to both adaptive and problematic behavior. In: Lilienfeld, S.O., O'Donohue, W.T. (Eds.), The Great Ideas of Clinical Science: 17 Principles That Every Mental Health Professional Should Understand. Routledge, New York, pp. 187–218.

Timberlake, W., Allison, J., 1974. Response deprivation: an empirical approach to instrumental performance. Psychol. Rev. 81, 146–164. https://doi.org/10.1037/h0036101.

Timberlake, W., Grant, D.L., 1975. Auto-shaping in rats to the presentation of another rat predicting food. Science 190, 690–692. https://doi.org/10.1126/science.190.4215.690.

Timberlake, W., Lucas, G.A., 1985. The basis of superstitious behavior: Chance contingency, stimulus substitution, or appetitive behavior? J. Exp. Anal. Behav. 44, 279–299. https://doi.org/10.1901/jeab.1985.44-279.

Timberlake, W., Lucas, G.A., 1989. Behavior systems and learning: from misbehavior to general principles. In: Klein, S.B., Mowrer, R.R. (Eds.), Contemporary Learning Theories: Instrumental Conditioning Theory and the Impact of Biological Constraints on Learning. Erlbaum, Hillsdale, NJ, pp. 237–275.

Timberlake, W., Lucas, G.A., 1991. Periodic water, interwater interval, and adjunctive behavior in a 24-hour multiresponse environment. Anim. Learn. Behav. 19, 369–380. https://doi.org/10.3758/BF03197898.

Timberlake, W., Silva, F.J., 1994. Observation of behavior, inference of function, and the study of learning. Psychon. Bull. Rev. 1, 73–88. https://doi.org/10.3758/BF03200762.

Timberlake, W., Wahl, G., King, D., 1982. Stimulus and response contingencies in the misbehavior of rats. J. Exp. Psychol. Anim. Behav. Process. 8, 62–85. https://doi.org/10.1037/0097-7403.8.4.328.

Tinbergen, N., 1951. The Study of Instinct. Oxford University Press, Oxford, England.

Verplanck, W.S., 1995. Some reflections on Kantor, Kantorians, and Kantor's career. Interbehaviorist 23, 6–12.