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THE ROAD FROM LEVER-PRESS TO GPS

EL CAMINO DE LA PRESIÓN A LA PALANCA AL GPS

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Abstract

B.F. Skinner developed the operant laboratory using electromechanical technology available in the 1930s. Since then, electronics and digital computers have changed the way in which events are recorded, and experiments programed and controlled. However, the essential features of the operant *preparation* (a set of instruments, concepts, and procedures seamlessly integrated to reliably render samples of operant behavior) have remained for the most part intact. Years of accumulated knowledge may be necessary to understand the extent of a model's capacity and limitations. In the case of the operant preparation, a number of important limitations to its original accepted validity have appeared over time, derived from new data and more inclusive theoretical frameworks. The aim of this paper is to examine the significance of the operant assay, and to consider potential extensions to incorporate dimensions of behavior made possible by new and emerging theories and technologies.

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Keywords: Operant behavior, experimental preparation, Skinner box, lever press, global positioning system, GPS, laboratory equipment, instrumentation.

Resumen

B.F. Skinner desarrolló el laboratorio operante usando tecnología electromecánica disponible en la década de 1930. Desde entonces la electrónica y las computadoras digitales han cambiado la forma en la que se registran los eventos y se programan y controlan los experimentos. Sin embargo, las características esenciales de la *preparación* operante (un conjunto de instrumentos, conceptos y procedimientos integrados eficientemente para producir confiablemente muestras de conducta operante) han permanecido, en su mayor parte, intactas. Pueden ser necesarios años de conocimiento acumulado para entender la extensión de las capacidades y limitaciones de un modelo. En el caso de la preparación operante, han aparecido un número importante de limitaciones a su validez aceptada inicialmente, derivadas de nuevos datos y marcos teóricos más inclusivos. El propósito de este trabajo es examinar el significado del ensayo operante y considerar posibles extensiones para incorporar dimensiones de la conducta que podrían ser posibles gracias a las nuevas y emergentes teorías y tecnologías.

Palabras clave: Conducta operante, preparación experimental, Caja de Skinner, presión a la palanca, sistema de posicionamiento global, GPS, equipo de laboratorio, instrumentación.

The development of new instruments has enabled many important discoveries in science by opening entire worlds for exploration (as did telescopes, microscopes, and X-ray imaging), and by augmenting the speed and precision afforded to scientific observations (as do clocks, lasers, and computers). In psychology, groundbreaking research has similarly been made possible by advances in instrumentation. It is no coincidence, for example, that B.F. Skinner, one of the most important contributors to modern psychology, was also a great instrumentalist. Skinner's (1956) detailed account of the evolution of his laboratory equipment, which culminated with the invention of the operant chamber, is a testament to both his ingenuity, and his impeccable scientific ethic. Unbounded by preconceived notions of the final products, he allowed his findings to guide the development of his research instruments, and then applied the same powerful inductive method to the construction of an entire psychological system. The clarity of his ideas, the elegance of the experiments, and the ease with which the results could be replicated and extrapolated to human behavior soon attracted entire generations of students who, like me, became followers and believers. To us, suddenly, everything made more sense. Eighty-plus years after the publication of his seminal work (1935), the impact of Skinner's contributions to the study of behavior is evident in many fields including psychology, pharmacology, ethology, neuroscience, and economics.

Skinner developed the operant laboratory using electromechanical technology available in the 1930s. Since then, electronics and digital computers have changed the way in which events are recorded, and experiments are programed and controlled. However, the essential features of the operant *preparation* have remained for the most part intact. The aim of this paper is to examine the significance of the operant assay, and to consider potential extensions to incorporate dimensions of behavior made possible by new and emerging theories and technologies.

The operant preparation

Through systematic tinkering Skinner developed a laboratory preparation; that is, a set of instruments, concepts, and procedures seamlessly integrated to reliably render samples of operant behavior. The preparation included an organism, a clearly defined response, an experimental environment, a clearly defined reinforcer, programming and recording equipment, a set of operations to establish, maintain, and motivate responding, and a research methodology based on single-subject designs (Ferster, 1953). Over time, variations were introduced such using pigeons or electric shock but, for the most part, the essential elements have remained consistent to this day. Standardization of the laboratory procedures soon led to an upsurge in the number of articles published, the creation of a specialized journal, and the establishment of businesses to manufacture and market operant laboratory equipment. It is safe to say that by creating the operant preparation Skinner opened a new world for exploration and made it possible for others to join in the adventure.

In science, the careful utilization of standardized equipment and procedures naturally leads to highly reliable observations that are also consistent across laboratories. Reliability and replicability are essential elements for any science to progress. Validity, on the other hand, mostly depends on the extent to which real-world phenomena are represented in the preparation. In part because the preparation is an abstraction of both the organism and the environment, its validity may not easily be gauged *a priori*. Years of accumulated knowledge may be necessary to understand the extent of a model's capacity and limitations. As we will see, in the case of the operant preparation a number of important limitations to its original accepted validity have appeared over time, derived from new data and more inclusive theoretical frameworks. At the same time, the operant methodology remains the gold standard for operant behavior research. In the following paragraphs I will touch on some of the concepts and data, mostly emanated from behavior analysis, that have circumscribed the theoretical place of observations made with the operant preparation, and will discuss potential benefits of incorporating newer methods and instruments into behavior analysis. This essay is offered as a selective informed account of significant issues in the evolution of the experimental analysis of behavior, not as a comprehensive analysis of the vast literature.

Digitization of the Behavior Stream

Adding the response lever was a key step in the search for a valid, economic, and automatically measurable aspect of eating behavior in the rat (Skinner, 1956). But it was not long before the lever-press response revealed the viability of a functional unit of behavior (the operant) sensitive to environmental changes, and representative of a much broader range of phenomena. The lever-press and the key-peck soon after, became standard units of operant behavior in the research laboratory. Digitization of the behavioral continuum into responses and response classes was a tremendous contribution, as it made possible the study of behavior of the organism free from the restrictions inherent in trial-by-trial methods, and allowed for the dynamic analysis of freely occurring behavior over time. It brought to light *response rate* as a critical aspect of the acquisition and maintenance of behavior. Nevertheless, because the control and recording equipment is activated by a switch in the operandum, it simultaneously defined the behavior that was *not* available for study in the chamber --namely, everything else. Clearly, limiting the observations in this way was a natural consequence of the success achieved by studying the lever-press, and not the product of a deliberate plan to exclude any form of behavior from scientific study. Skinner's (1948) own finding that regular delivery of response-independent food is sufficient for the development of "superstitious" behavior, revealed that in the operant chamber patterns of behavior can develop that are not recorded or analyzed, and opened up the possibility that the accepted theoretical account of what happens in the box was, at best, incomplete. Staddon & Simmelhag (1971) and Timberlake & Lucas (1985) later demonstrated the appearance of systematic patterns of elicited and induced behavior in relation to food deliveries, supporting alternative interpretations of contingencies as environmental constraints (Premack, 1965; Timberlake & Allison, 1974) that alter the allocation of behavior over time. Thus, while the operandum permitted digitizing of behavior into discrete responses and yielded a stable behavior sample to work with, it did not facilitate the assimilation of important phenomena like *induction* into a more inclusive theoretical account of behavior in the operant chamber.

Operant-Respondent Interaction

Participation of respondent-like processes in the operant chamber became evident with the discovery of adjunctive behavior. Following Falk's (1961) finding that intermittent food presentation results in excessive consumption of water in the rat, others have shown that pica, escape, attack, wheel running, air licking, and sugar, alcohol, and nicotine consumption occur with a variety of organisms exposed to intermittent reinforcement. In humans, adjunctive behavior has been shown to include clinically important behavior such as polydipsia, smoking, eating, and locomotor activity. Then, Brown and Jenkins (1968) discovered that repeatedly pairing the illumination of the response key with the presentation of food reliably leads to key pecking in pigeons. The procedure did not require shaping or a contingency relationship between key-peck and food and, once established, responding could still be maintained when it turned off the key light and prevented the presentation of food (Williams & Williams, 1969). Auto-shaping was also observed in rats under various conditions (Atnip, 1977; Peterson et al., 1972; Timberlake & Grant, 1975), and in other species. Furthermore, an elegant study by Schwartz (1977) showed that in a baseline maintained by a VI 1-minute schedule of food reinforcement there are two types of key-pecks identifiable by their duration, with short-duration responses being insensitive to their consequences. Taken together, these results strengthened the notion that Pavlovian-like relations between stimuli that do not involve operant conditioning contribute to the phenomena taking place and being recorded in the operant chamber.

Schedules of Reinforcement

Much basic research in the field of operant conditioning has been devoted to understanding how schedules of reinforcement exert control over behavior. In particular, much effort has been devoted to understanding the quantitative relationships between reinforcement and responding in concurrent schedules. Herrnstein's (1961) discovery of the Matching Law lead to the establishment of a number of systematic relations between behavior and various aspects of the reinforcer and the reinforcement schedules, and spurred the use of quantitative models in behavior analysis. In turn, these relations and models have served to stimulate theoretical development, as more precise hypotheses can be postulated and tested, and to make operant conditioning methods more useful in other fields where, as in behavioral pharmacology, comparisons between quantitatively and qualitatively different reinforcers are often necessary. However, research conducted from a behavior economic perspective, (e.g., Hall & Lattal, 1990; Hursh, 1984) has revealed that *matching*, the seemingly universal quantitative relation between behavior and reinforcement observed in the laboratory, depends on two other elements of the operant preparation: short experimental sessions and supplemental feeding in the subject's living cage.

A necessary condition to achieve consistent responding during operant conditioning sessions is a relatively constant level of motivation to respond (amount of deprivation). As subjects consume food during the session, however, the level of deprivation decreases, imposing a practical limit to the number of food pellets that can be consumed in a session before they have an effect on responding. Thus, to guarantee consistent conditions throughout the study, the subjects are regularly maintained at about 85 % of their free-feeding weight and, to compensate for deficits in consumption during sessions, the animals receive supplemental free food in their cages after each session. In other words, they live in an open economy with more than one source of "income," session pellets and free chow. A central concept in behavioral economics is that, other things being equal, as the price of a commodity increases, responding increases (up to a point) to keep up the level of consumption and that, symmetrically, lower prices lead to lower responding. In other words, that a lower rate of reinforcement will lead to more responding and that a higher rate of reinforcement will have the opposite effect. That, of course, is contrary to what the matching law predicts. Taking into account the effect that consumption of the reinforcers has on further responding, as in a closed economy, leads to behavior functions that more resemble economic demand models than matching (e.g., Green & Freed, 1998). In addition, two other factors have not been sufficiently investigated within the operant preparation, a) comparing heterogeneous reinforcers in choice studies, and b) having more than two alternatives to choose from. Incorporating these variables into operant studies of choice would most likely (Hursh, 1984) produce responding not readily described by the matching law; instead, economic concepts of elasticity, intensity, substitutability, and complementarity would be necessary to adequately describe choice/demand. To be sure, while the integration of other and different reinforcers, and the use of closed economies does not invalidate the wealth of knowledge previously acquired on operant choice, results from behavioral economic studies suggest that a more comprehensive and more generally valid framework can be achieved.

Steady-State Performance

Behavior under most schedules of reinforcement becomes very stable over successive sessions. In part because stable performances make for better baselines from which to assess the effects of other independent variables, much of the research in operant conditioning has involved steady state performance achieved over dozens or hundreds of short training sessions. Perhaps another reason for the consistent use of steady-state baselines in operant research is that before computers were available in the behavior lab it was extremely difficult to gather, store, and analyze data on individual responses. Therefore, the learning and adaptation that occur when experimental conditions change were for the most part, treated as transitions between steady states, which although governed by the same behavior principles, were for practical purposes, out of reach. The availability of computers has made it easier to assess the effect that individual presentations/omissions of a stimulus might have on future responding (Davison & Baum, 2003), and has facilitated the study of within-session adaptation to environmental changes as more than transition between steady states (Cowie & Davison, 2016). Skinner defined a reinforcer as a stimulus that when presented following a response will increase the future probability of that response. We can now directly assess the reinforcing and discriminative effects of individual presentations of a stimulus.

The findings described above serve here to exemplify aspects of the operant preparation that were not clearly evident when Skinner proposed his research methodology and psychological system. Taken together, these and other issues have served to reassess the place of operant behavior and operant conditioning among all psychological processes. In my view, they point toward an understanding of behavior as a generalized adaptation system, where operant conditioning is one of the inseparable participating mechanisms, along with classical conditioning and induction by other contextual factors. Nevertheless, as the conceptualization of what takes place in the operant chamber evolves, the utility of the operant preparation in behavioral research has not diminished.

Expanding the Scope

One important recent theoretical contribution is the push for a molar analysis of behavior, i.e., the description of behavior not in terms of individual responses and classes but as activities extended over time (Baum, 2002). This conceptualization allows for the incorporation of phenomena like respondent processes and other forms of contextual induction in behavior analysis, and makes possible the study of behavior as time allocation in relation to biological demands, and environmental resources and constraints. As described earlier, Skinner's operationalization and digitization of eating behavior in terms of the lever-press effectively broke down a continuous activity (feeding) into measurable bits sensitive to contingencies of reinforcement. However, feeding, the original behavior of interest, remained the complex continuous activity extended over time that it is today.

In an attempt to expand the capacity to capture more of what takes place in the operant chamber, a system has been proposed (Robles, 1990) where behavior not captured by activation of the operanda could be described by its spatial and temporal dimensions in relation to known features in the environment. The chamber was a 1 m^2 arena that could be fitted with various operanda, liquid and food dispensers, nesting material, and other features. A grid of infrared sensors sampled the location of the rat every 5 s, and stored the information as a time-indexed sequence of x, y coordinates. So, the system provided a digitized account of the animal's behavior in time and space that, along with discrete responses like lever activations, afforded a more comprehensive picture of all behavior over time. The resulting data could be used to identify patterns of behavior such as general locomotor activity, exploration, feeding, sleeping, and so on. The data could also be processed to generate molar accounts of behavior as relative probabilities over time. More refined prototypes were later built that used high resolution cameras to capture images and location coordinates, but the essential qualities of the system were maintained. Although the proposed system has not yet had an impact on operant research, unrelated advances in communication technologies have now opened the possibility to study human behavior by using concepts and analytics similar to those proposed by Robles (1990). The widespread use of global positioning satellite (GPS) data in personal mobile devices effectively permits to generate a time-indexed sequence of *x*, *y* values that, when superimposed on digital maps enables the quantitative description of behavior as time allocation in relation to the environment. If the account of behavior is based on the distribution of activities in time instead of individual stimuli and responses, the information obtained from GPS data can be used to describe much of the daily behavior of individuals and groups. In addition to gross patterns of behavior such as traveling, working, exercising, shopping and so on, finer analyses are possible by increasing the resolution of the digital maps (Baum & Rachlin, 1969; Pear, 1985), by generating behavior "inventories" based on the probability of behaviors occurring in various sites (grocery stores, churches, stadiums, etc.), and by incorporating other digital markers to time-space-context data, such as purchases and access to internet pages. Clearly, many ethical considerations are pertinent here. At the same time, because we routinely allow phone apps to collect GPS location information, this type of analysis is now regularly conducted by corporations and used for marketing purposes. In my view, behavioral psychology has much to gain from molar analyses of animal and human behavior based on time-space-context data; in turn, those important scientific discoveries should be universally shared for the benefit of all.

The Road Not Yet Taken

A fundamental tenet of radical behaviorism is that all of the organism's activity *is* behavior. Historically, the distinction was important to account for activity that could not be directly observed and measured, such as feelings and thoughts, that occur in the intact organism. But while adopting radical behaviorism satisfied the need for ontological congruency, in practice, behavioral psychologists have yet to systematically study those phenomena. Verbal behavior is perhaps where most of the effort has been placed to date; however, compared to other areas, progress there has been relatively slow. The process is further complicated by the relative independence between form and function. Still, incorporating these phenomena within some expanded version of the existing theoretical framework of behavior analysis would much enrich the field and our understanding of human behavior in ways in which cognitive psychology may not facilitate. Recent advances in instrumentation now enable the measurement of various forms of motor behavior that are highly correlated with emotional states and cognition. For example, computerized face recognition technology makes it possible to continuously identify both gross and fine changes in expression otherwise inaccessible to the naked eye. It is possible, for example, to use these data to study the potential function of emotions as discriminative stimuli (Wang, Huang, & Makedon, 2014), or to gauge the subjective value of stimuli presented on a screen during the estimation of delay or social discounting. Similarly, it is now possible to obtain from eye trackers continuous records of what a person is attending to (Adam, Bays, & Husain, 2012). These records include velocity and duration of saccades that correlate with the subjective value of the stimuli, and continuous measurements of pupil diameter, a reliable indicator of cognitive effort. The systematic analysis of body language, as a dynamic concomitant of verbal behavior, is now possible with computerized integration of signals from cameras and other sources (Duran et al., 2013). And an inexpensive and effective measure of cognitive and emotional precursors of choice can obtained from a mouse tracker, a piece of computer code that records the physical path of the computer mouse during choice procedures (Koop & Johnson, 2012; Scherbaum, et al., 2016).

Skinner attempted to develop teaching machines that would shape a person's knowledge through meaningful feedback and differential contingencies. The task was very laborious and complex because the medium was limited to paper, and there was no way to make branching as adaptive and personal as necessary. With the Internet, along with personal computers, tablets and telephones, the mother of all teaching machines is now possible, unlimited in its capacity for personalization, content, media, portability, and speed. Anything Skinner dreamed a teaching technology could be is now possible at a level that even he might have had trouble imagining. There has never been so much technological support to study environment-behavior interactions, and to develop and implement individualized behavior change interventions like those recently created for clinical applications (Carroll et al., 2014; Dallery & Raiff, 2011; Stedman-Falls & Dallery, 2017 [this issue]; Vargas et al., 2010).

Final Remarks

These are but a few potential applications of newly developed instruments in areas where behavioral psychology can grow. It seems as if faster and more precise instruments for the measurement and analysis of behavior and the environment become available at an increasingly accelerated pace. But, although throughout history new instruments have opened up entire fields for study, having access to new data is only part of the equation.

The research methods created by B.F Skinner supported the development of a highly productive psychological system that continues to bear fruit after more than eighty years. While the conceptualization of operant behavior as it occurs in the chamber has evolved as a result of new findings and more comprehensive theoretical frameworks, the laboratory preparation remains an effective and efficient test bed for behavioral experimentation. There are now plenty of opportunities to advance behavior analysis in areas where limitations in instrumentation prevented growth in the past. Behavioral psychologists have a strong formation in experimental methods and a fierce inclination to remain objective and unaccepting of mentalistic constructs. For that reason, they are specially well equipped to tackle the study of phenomena that Skinner and many others could not. At this stage in de development of behavioral psychology, it is limitations in theory, imagination, and consensus among peers that hinder progress, not scarcity of powerful tools.

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