JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2006, **86,** 371–384 NUMBER 3 (NOVEMBER)

ROGER T. KELLEHER, BEHAVIOR ANALYST

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Roger T. Kelleher, rightly known as one of the foremost contributors to behavioral pharmacology, also made many important contributions to the experimental analysis of behavior. He participated significantly in the development of the discipline, through both his research and his editorial contributions to this journal. This article summarizes his contributions to the field of behavior analysis. His most significant empirical and conceptual contributions to behavior analysis came in two domains—conditioned reinforcement and the power of schedules of reinforcement. His accomplishments in these two domains still serve as principal foundations for modern research and theory.

Key words: Roger T. Kelleher, biography, conditioned reinforcement, reinforcement schedules, second-order schedules

The late Roger T. Kelleher (1926–1994) is deservedly and widely recognized for his contributions to behavioral pharmacology. Less commonly appreciated is his work in the experimental analysis of behavior, and thus the major focus of this paper is to summarize his contributions to behavior analysis. The review is intended to reveal that Roger Kelleher played a principal role in the development of the field, and that his research contributions endure. What follows is an overview of Roger's research on behavior. Emphasis is given to the importance of the research at the time it was done, its lasting impact, and on interesting questions raised—questions that remain unanswered.

Kelleher received his Ph.D. from New York University in 1955. He published two papers based on his work as a graduate student. The first (Kelleher, 1955), derived from his Master's thesis, explored the role of randomizing the order of questions on a vocational inventory. The second, based on his doctoral dissertation, involved the use of traditional between-groups designs to investigate how discriminative training in a maze influenced the development of subsequent discriminations (Kelleher, 1956a). Upon receiving his doctorate, he moved to the Yerkes Primate Research Facility at Orange Park, Florida where he worked with Charles Ferster. The research he conducted there was his first using individual-subject designs. After a brief but productive stay at Yerkes, Kelleher moved to Smith, Kline, and French laboratories, and shortly thereafter to the Harvard Medical School where he remained for the rest of his career. Significant behavioral research was accomplished at all three sites. Roger served two terms on the *JEAB* editorial board, from 1961 to 1964, and 1968 to 1971. In between those two terms, he held the position of Associate Editor for the journal from 1964 through 1967. Those appointments serve as testimony to how he was perceived by his peers in behavior analysis during the formative years of the discipline.

Figure 1 provides an overview of Kelleher's publications that focused on behavioral issues. (His work in behavioral pharmacology, which is voluminous, is not represented.) He was continually active in basic behavioral science from the time of receipt of his doctorate until well into the 1970s. This work was of considerable impact. A citation count indicates that the publications on which Figure 1 is based have been cited more than 1500 times (http://webofscience.com/).

Kelleher's contributions to behavior analysis fell mainly into three domains. First, and most extensive, was his research on conditioned reinforcement. Second, he also made significant contributions in the area of schedules of reinforcement, with special emphasis on how the study of schedules has yielded important

Preparation of this article was supported by grants DA04074 and DA14249 from the National Institute on Drug Abuse. Reprints may be obtained from the author at the Psychology Department, Box 112250, University of Florida, Gainesville, FL 32611. E-mail inquiries can be made to branch@ufl.edu.

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doi: 10.1901/jeab.2006.25-06

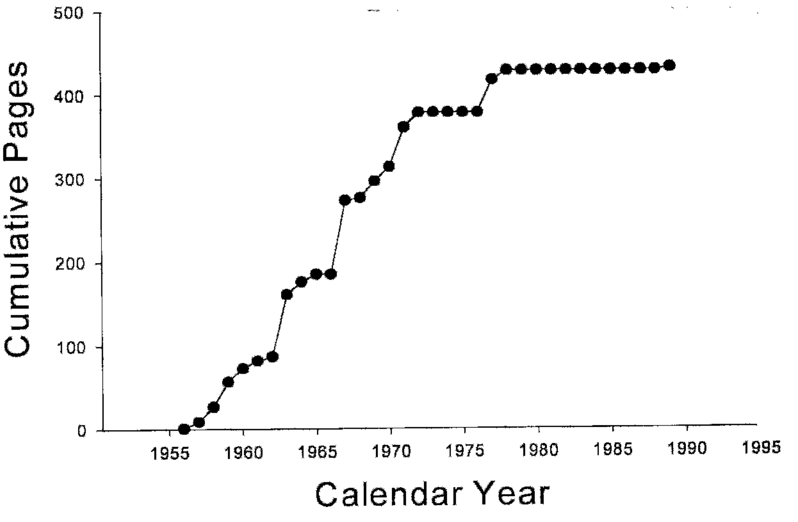

Fig. 1. Cumulative pages published by Roger T. Kelleher over the years 1955 to 1990. Only publications focused on the analysis of behavior are included.

implications for fundamental conceptualizations in the science of behavior. Third, Roger published several papers that can be categorized as constituting service to the discipline, both in the form of technical contributions and conceptual ones.

SCHEDULES OF CONDITIONED REINFORCEMENT

Kelleher's contributions to the study of conditioned reinforcement, both theoretical and empirical, are seminal to the field. He authored the two major reviews on conditioned reinforcement that appeared in the 1960s (Kelleher, 1966a; Kelleher & Gollub, 1962). These two papers remain on a "must read" list for anyone interested in studying conditioned reinforcement. He also pioneered the development of two of the most important procedures used to study conditioned reinforcement.

Kelleher, as will become increasingly clear through this review, was one of the first to appreciate the power of schedules of reinforcement to analyze psychological theory. His insights in this realm are made especially clear in a major publication concerning conditioned reinforcement (Kelleher, 1961). At the time this paper was published most of the literature on conditioned reinforcement consisted of studies employing extinction procedures showing small, often ephemeral, effects. Existing research had focused on increases in the probability of behavior when putative conditioned reinforcement was added to the situation, and changes in behavior were often small enough for interpretations based on processes other than conditioned reinforcement to be invoked. For example, one view was that the operations presumed to imbue a stimulus with efficacy as a conditioned reinforcer did not do so. Instead, these operations were suggested to produce more generalized excitatory effects (e.g., Bitterman, Fedderson, & Tyler, 1953; Bugelski, 1956: Wyckoff, Sidowski, & Chambliss, 1958), implying that any increases in performance were due to factors other than conditioned reinforcement.

In research challenging these suggestions, Kelleher (1961) took advantage of intermittent reinforcement in two ways. First, he established performance under a relatively high-valued fixed-interval (FI) schedule of food presentation, an arrangement that produced prodigious resistance to extinction and therefore provided a substantial sample of behavior on which to superimpose putative conditioned reinforcement. Second, he presented the stimulus suspected to be capable of acting as a conditioned reinforcer (the sound of the food hopper) on various schedules, each known to produce particular patterns of performance. Figure 2 shows the results. The top panel shows data from the first session of

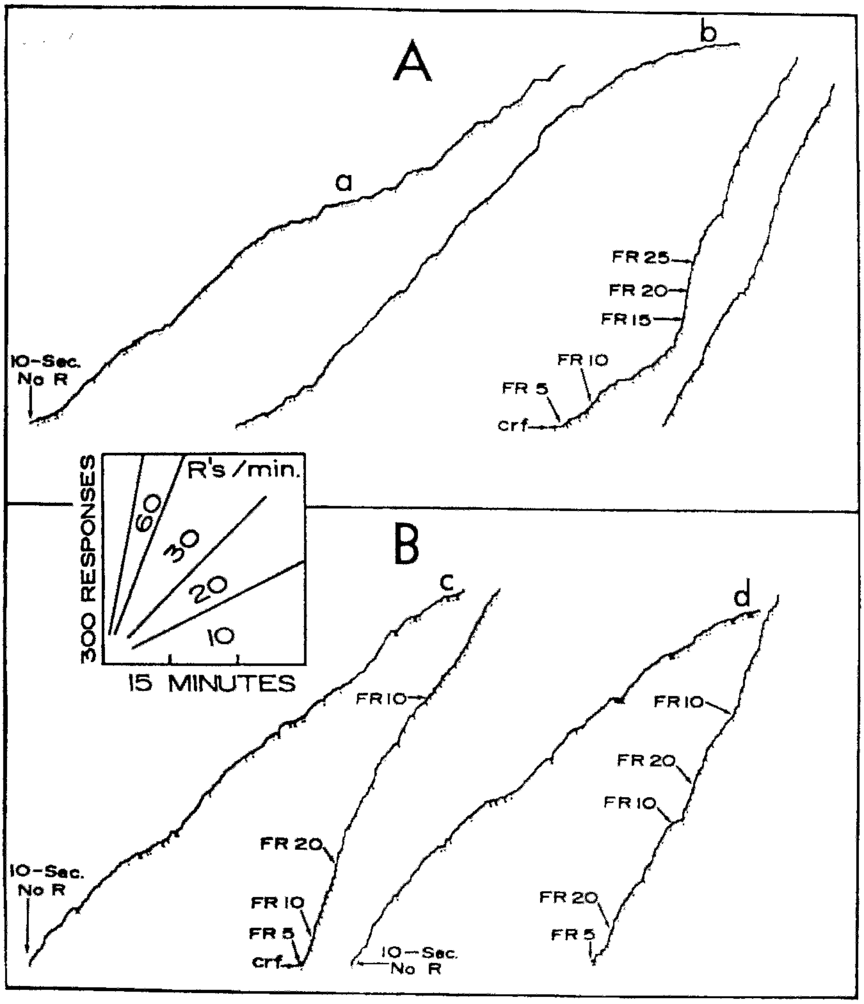

Fig. 2. Cumulative records of key pecking during two successive daily sessions; Panel A is from the first session; Panel B is from the second. No food was delivered, but brief operations of the empty feeder, indicated by "pips" on the records, occurred according to the schedules designated on the records. Arrows denote where schedule conditions changed; "crf" means FR 1. Sections near a, b, c, and d show low rates with frequent presentations of the hopper sound. (From Kelleher, 1961).

testing; the lower shows the second. No food was presented, and the really clever idea that Kelleher had was to use schedules that would either increase the frequency of behavior or decrease it. Specifically, he presented the stimulus (the operation of the empty feeder) according to either a differential reinforcement of other behavior (DRO: denoted as 10-Sec No R in the figure) schedule or a fixed-ratio (FR) schedule. The DRO schedule resulted in lowered rates, whereas the FR schedules led to increased rates. The contrast is especially obvious in Panel B where changes in schedule resulted in a two- to three-fold difference in response rate. Accounts based on general excitation cannot accommodate these results, whereas they fit well with the notion of conditioned reinforcement—any reinforcer should control performance appropriate to the schedule of that reinforcer.

Ironically, by the time this paper was published, Kelleher had already published five papers emanating from his work at the Yerkes Primate Center. All these articles focused on conditioned reinforcement, and he took advantage of current developments in the study

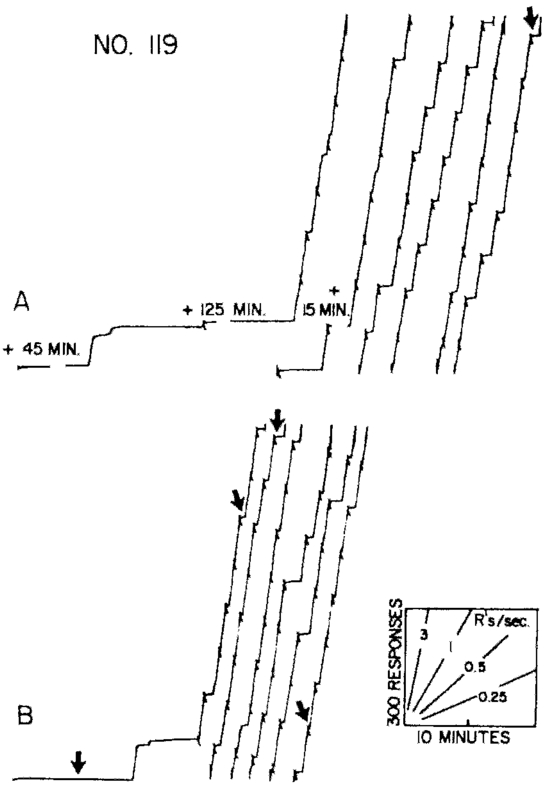

Fig. 3. Cumulative records of key pressing by a chimpanzee under a fixed-ratio schedule of token production. Token deliveries are indicated by ''pips'' on the records. Arrows indicate points at which tokens were deposited prematurely. In the lower record, extra tokens were provided at the beginning of the session. (From Kelleher, 1958b).

of schedules of reinforcement to engender large amounts of behavior with conditioned reinforcement. Four of the papers (Kelleher 1956b, 1957a, 1957b, 1958b) illustrated the phenomenon of *token reinforcement* in chimpanzees. Chimps were trained to exchange poker chips for food, and then a variety of FR schedules of earning tokens were studied. As described in the fourth paper, Kelleher established responding for token delivery under schedules as large as FR 125, and that behavior was maintained even when up to 60 tokens had to be accumulated before exchange for food was possible. That is, upwards of 7000 responses were maintained by conditioned reinforcement, hardly a small or ephemeral effect. Figure 3 shows cumulative-response records of performance under an FR 125 schedule of token presentation. Record A shows data from a standard session in which tokens could be exchanged after 50 had been accumulated. The record in B is from a session in which 50 tokens were given ''for free'' at the beginning of the session, but 50 more had to be earned before exchange was effective. Solid arrows show where ''premature'' deposits of tokens occurred (these tokens were wasted). Of particular note is the schedule-appropriate responding that developed. Not only did token presentation maintain a substantial amount of responding, it also produced schedule-typical responding, additional evidence that token presentation was functioning as reinforcement.

The fifth paper that resulted from Kelleher's research at the Yerkes site was equally seminal. This was the first of a pair of papers, one with chimps as subjects (Kelleher, 1958a) and a subsequent paper with pigeons (Kelleher, Riddle, & Cook, 1962), on *observing responses.* In the chimpanzee study, Kelleher established key pressing, using food as reinforcement, under a multiple variable-ratio (VR) 100-extinction (EXT) schedule. Later, responses on a second key (''observing key'') resulted in 30-s presentations of the discriminative stimuli associated with the two components of the schedule. In the absence of presses on the observing key, the VR and EXT components continued to be in effect in a mixed sequence without associated discriminative stimuli. Several FR values on the observing key were examined with the result that schedule-appropriate patterns of behavior were well maintained on that key. An important control procedure also was employed. In one condition, the observing response continued to produce presentations of the two discriminative stimuli, but there was no relation between a presentation of a particular stimulus and whether VR or EXT was in effect. Observing rate declined, indicating that the stimuli had to be reliably correlated with the food reinforcement schedules in order to function as an effective reinforcer for observing. In the 1962 paper the method was adapted for pigeons with similar results.

Kelleher's main contributions to the study of observing responses were twofold. First, he used an arbitrary observing response, a key press with the chimps or a key peck with pigeons, an advance over previous procedures. For example, in the original method for pigeons, as devised by Wyckoff (1952), a floor-panel press had been employed. The operant level of panel pressing was substantial, making it somewhat difficult to quantify behavior under the control of the observing contingency separately from general activity. Second, Kelleher studied observing responses under intermittent reinforcement, again bringing the power of reinforcement-schedule control to bear on the study of behavior maintained by conditioned reinforcement. These innovations remain standard today, and the observing-response procedure is a staple of research on conditioned reinforcement.

In a short, but important conceptual leap from token reinforcement, Kelleher was instrumental also in the development of *second-order schedules* to study conditioned reinforcement. He published only one paper devoted solely to behavioral issues on the topic, but it remains a classic (Kelleher, 1966b). Here he defined the concept of a second-order schedule as one that "...treats a pattern of behavior engendered by a schedule contingency as a unitary response that is itself reinforced according to some schedule of reinforcement" (p. 476), and he also suggested a nomenclature for describing such schedules. In the research described in the paper, Kelleher studied schedules of the form FR *n* (FI *t*). That is, performance under an FI *t* schedule was treated as a unitary response that was reinforced according to an FR *n* schedule. Conditioned reinforcement was studied by adding brief stimuli (0.7-s presentations of a white key light) at the end of each FI *t*. Schedule parameter values were selected such that the primary reinforcer, access to food, was available, at a minimum, only once per hour [FR 15 (FI 4 min: W) where W refers to the white key light that was paired with food presentation]. An example of performance is shown in Figure 4. The upper and lower cumulative records show performance of a pigeon under the FR 15 (FI 4 min: W) schedule. The middle record shows performance under an FR15 (FI 4 min) schedule in which 15 consecutive FI 4-min schedules had to be completed, but no stimulus change accompanied the completion of each FI. The dramatic differences in rate and temporal patterning illustrate the importance of the brief stimuli in supporting the extended sequence of behavior. As Kelleher so aptly noted, "Long and orderly sequences of

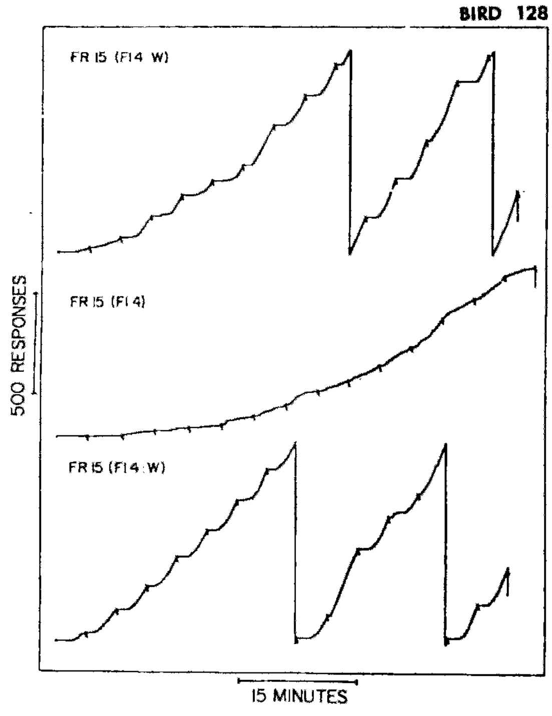

Fig. 4. Cumulative records of key pecking under a second-order fixed-ratio 15 (fixed-interval 4-min) schedule. Pips indicate completions of the FI schedule components. In the upper and lower records, completion of each FI resulted in brief presentation of a white key light. In the middle record, no stimulus change occurred at the end of each FI. (From Kelleher, 1966b).

responses...uninterrupted by primary reinforcement endow behavior with much of its apparent purposefulness" (p. 475). As he showed, such sequences can arise under second-order schedules, and their orderliness is a function of the presentation of brief stimuli.

This report describing second-order schedules also presented an intriguing result that has not been pursued. The effect is summarized in Figure 5. Shown are response rates averaged separately over the successive four minutes of each FI 4 min. The circles show data when the brief stimulus (white key light) was presented at the end of each FI, and they summarize the patterning evident in Figure 4. Response rates within each FI began with lower rates and ended with much higher rates. Of particular interest, however, are the triangles, which display rates in each successive minute when a brief stimulus appeared at the end of each FI except the last of the 15. That

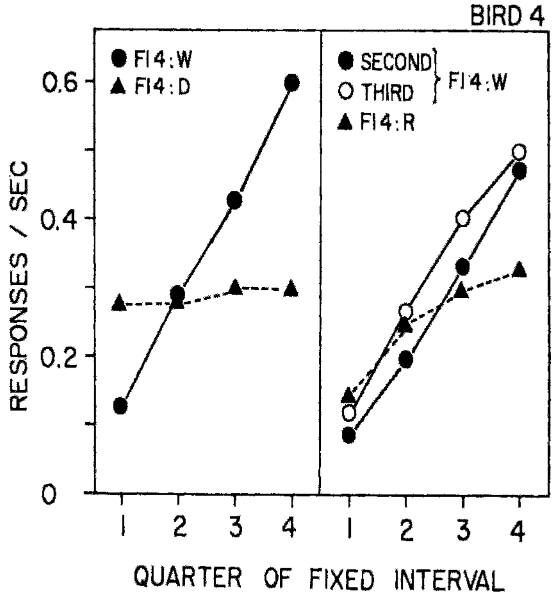

Fig. 5. Average response rates in successive 1-min segments of each FI 4-min component in the second-order FR 15 (FI 4-min) schedule. Circles show rates when each FI ended with a brief white stimulus. Triangles in the left panel show rates when all but the last FI in each sequence of 15 were followed by brief presentation of a dark key. Triangles in the right panel show rates when all but the last FI were followed by a brief presentation of a red key light. Open circles show data from a final condition in which the brief white stimulus once again followed completion of all components. (From Kelleher, 1966b).

is, the brief stimulus did not appear contiguous with access to food (''unpaired stimulus''). In the left panel, the data represented by the triangles are from a condition in which the brief stimulus consisted of darkening the key for 0.7 s. In the right panel, triangles show data from a condition in which the brief stimulus was a 0.7-s presentation of a red key light. Note the difference in effects of the dark-key versus the red key. The latter resulted in consistent temporal patterning, although not as dramatic as that resulting from the paired stimulus. The dark key, by contrast, led to virtually no patterning. Was the history with a paired stimulus (white key light) necessary for this difference to occur, or is there something about a brief period of dark key that renders it less effective in controlling behavior? Clearly, additional experiments would be needed to answer these and related questions.

A final important paper in the domain of conditioned reinforcement was Kelleher's analysis of stimulus functions in chained schedules (Kelleher & Fry, 1962). In this work with pigeons, Kelleher and Fry showed that the regular ordering of stimuli in a three-component chained schedule was crucial in the generation of the very weak behavior at the beginning of the sequence. If the stimuli were presented in an irregular order, not only was behavior at the beginning of the sequence well maintained, schedule-appropriate patterns of responding developed in each of the three components of the schedule. In fact, temporally patterned performance was more evident in the later components of the chain when the stimulus order was irregular than it was when the stimuli appeared in fixed order. This interesting finding remains largely unexplored (but see Byrd, 1971 and Marr, 1979).

SCHEDULES AS FUNDAMENTAL

As indicated by his work with conditioned reinforcement, Kelleher had a keen interest in the general significance of scheduling consequences for behavior. The second domain in which Kelleher made exceptional contributions was the systematic study of behavior–consequence relations. Over the decade from 1959 to 1969, Kelleher published eight papers on this theme. The first three of these concerned the precision of behavioral control that could be engendered by schedules of consequences, and the remaining five studied the effects of scheduling noxious events. The first paper (Kelleher, Fry, & Cook, 1959) described procedures for developing precise temporal control using differentiation of low rate (DRL) schedules and limited holds. Specifically, lever pressing by rats was studied under schedules in which interresponse times (IRTs) of 20 s or more could be reinforced. Limited holds, that is, fixed-duration periods during which a scheduled reinforcer could be obtained, began 20 s after the previous response. Thus, this procedure arranged a minimum and a maximum of IRTs that could be reinforced. Very precise temporal control was produced, with a vast majority of the IRTs occurring within the reinforced ''band.'' This study, then, provided powerful testimony that reinforcement schedules could generate and control behavior with precise temporal char-

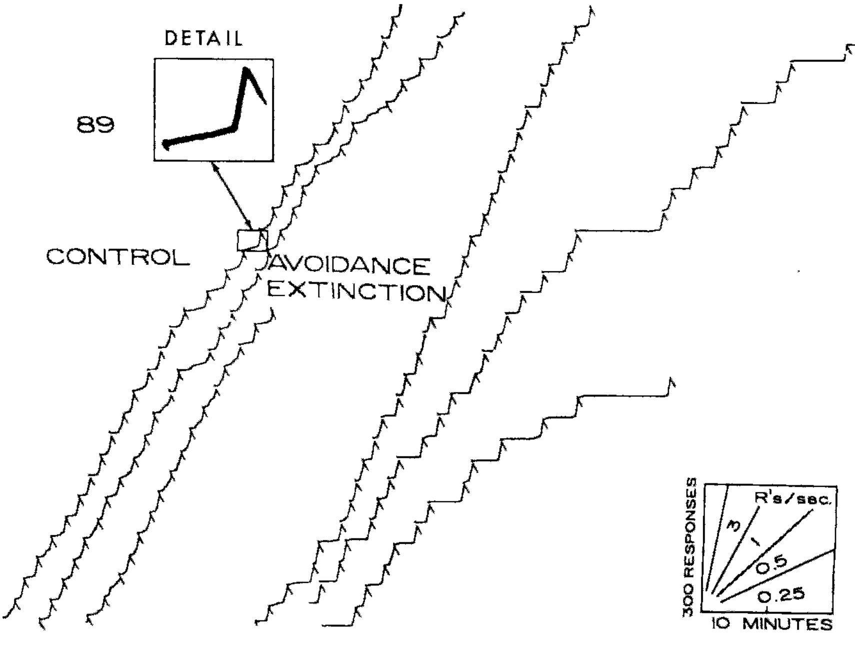

Fig. 6. Cumulative response records of lever pressing under a conjoint FR avoidance schedule (left record) or under a simple FR schedule. (From Kelleher & Cook, 1959).

acteristics. In addition, the study reports one of the earliest examples of a second-order schedule. In one phase of the experiment, only every second "correct" IRT was reinforced. That is, an FR 2 (DRL 20-s) schedule was employed, although it was not given that designation.

A second study (Kelleher & Cook, 1959) focused on the superposition of two contingencies of reinforcement. A single lever was available to the subjects (either rats or squirrel monkeys), and two schedules of reinforcement were simultaneously operative. Food pellets could be earned according to an FR schedule, and concurrently lever presses also postponed brief electric shocks (Sidman, 1953). In the absence of lever pressing, shocks occurred every 30 s, but each response postponed shock for 30 s. This study is significant not only for illustrating how simultaneous contingencies for a single response (now called a conjoint schedule) can both blend and exert independent control over performance, it also is the first illustration of an experimental strategy that appears in Kelleher's later work on behavior controlled by complex contingencies. The strategy is illustrated in Figure 6.

The cumulative record on the left shows performance, after some training, under a conjoint FR 50-avoidance schedule. As the enlarged inset shows, after each food presentation, a low, constant rate prevailed, followed by an abrupt transition to a high constant rate until the next food presentation. The record on the right shows performance in the second session during which only the FR 50 schedule was in effect. The low, moderate rates have disappeared, but the abrupt transitions to high constant rates remain present. In complementary experiments, the FR 50 schedule was removed, and only the low rate was evident. That is, the strategy to examine the contribution of each schedule was to remove it, then reintroduce it. The study showed convincingly how each schedule independently contributed to the overall pattern of behavior when both were simultaneously operative.

A third study (Kelleher, Fry, & Cook, 1964) treated completion of a fixed number of responses as a single response (much as in second-order schedules). In the first of two experiments, squirrel monkeys were exposed to a procedure in which delivery of a food pellet depended on the completion of a variable number (ratio) of lever presses. The number varied depending on the length of the pause at the beginning of previous ratios. If two successive pauses were shorter than

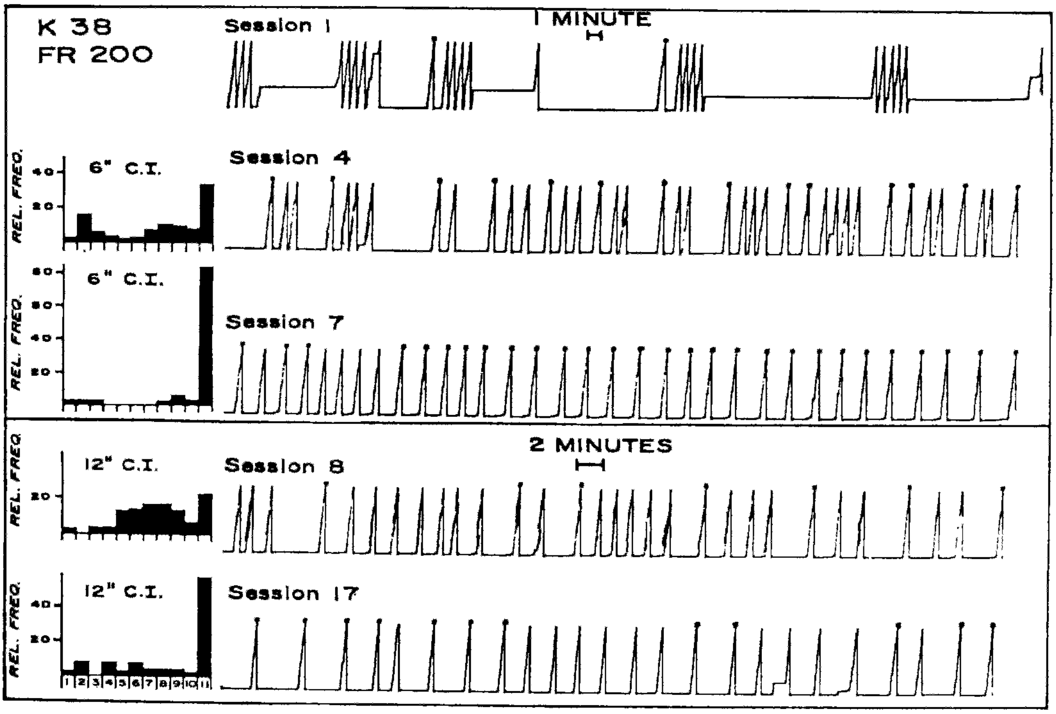

Fig. 7. Cumulative records of lever pressing from several sessions under a procedure in which completion of a fixed ratio ended with food if the pause prior to initiation of lever pressing exceeded a criterion. In the top three records, the criterion was 1 min; in the bottom two it was 2 min. Histograms at the left show frequency distributions of pause lengths; C. I. denotes the width of the class intervals for the frequency distributions. Sessions presented are indicated. (From Kelleher, Fry, & Cook, 1964).

a criterion value (which was manipulated systematically across phases of the experiment), then the ratio increased. If two successive pauses exceeded the criterion, the ratio decreased. Each session began with a ratio of 10, and the ratio, based on a monkey's performance, could reach a maximum of 1000. Under these circumstances, within each session the ratio attained grew initially and then oscillated around a mean value. The mean value grew with increases in the pause criterion. When the criterion was 1 min, ratio values grew to about FR 200. When it was 15 min, the mean ratio value was near 800. This study illustrated a dynamic interplay between a pausing criterion, similar to that arranged by a DRL schedule, and the magnitude of a response requirement.

In the second experiment in this paper, the length of the pause before the initiation of a fixed ratio determined whether food would be delivered at the end of the ratio. Essentially, this is a DRL schedule in which the "response" is the completion of a sequence of individual lever presses. Figure 7 shows results for one monkey responding under an FR 200 schedule. The top three records show beginning and later performance when the pause requirement was 1 min, and the lower records show the early and later effects of exposure to a 2-min pause criterion. The histograms to the left of each record summarize the distribution of obtained pauses. The pause durations conformed to the contingencies. These data are a powerful demonstration of the role of DRL-like contingencies having their usual effects even when the response unit is 200 separate lever presses. Subsequent research (e.g., Zeiler, 1970, 1972) has confirmed these significant and provocative results.

Of the remaining four empirical papers to be described, three were co-authored with W. H. Morse, and they recount a series of experiments with profound implications for understanding behavior–consequence relations. Each set of experiments reveals that

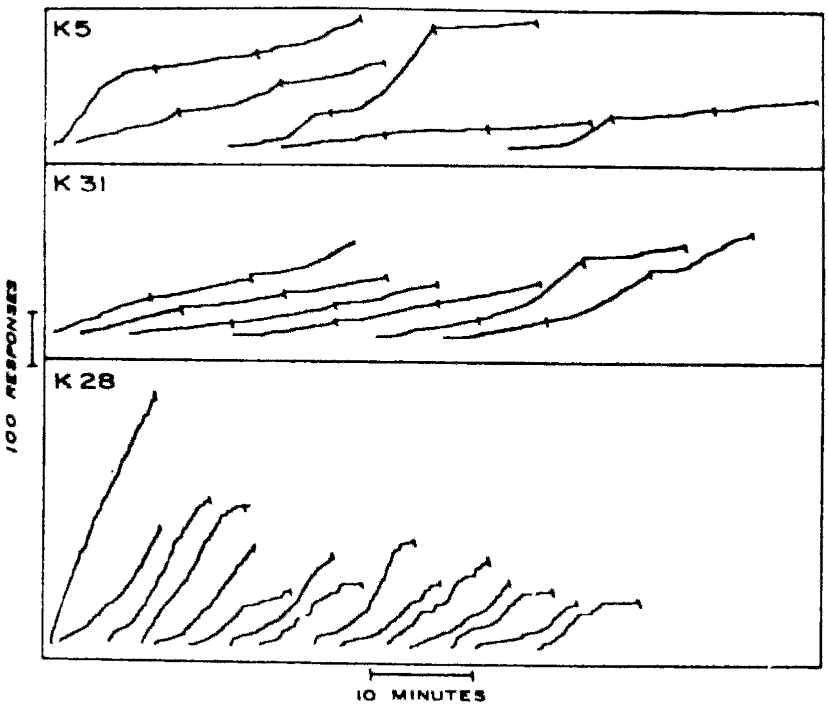

Fig. 8. Cumulative records of lever pressing by three squirrel monkeys under a fixed-time (FT) 10-min schedule of electric shock presentation. (From Kelleher, Riddle, & Cook, 1963).

the interplay of previous and current contingencies can result in behavioral control that is far from intuitive. In the first of the three (Kelleher, Riddle, & Cook, 1963), squirrel monkeys first were trained to press a lever under a multiple schedule in which 10-min periods of free-operant avoidance alternated with 10-min periods of a variable interval (VI) 1.5-min schedule of food presentation. Subsequently, during the 10-min VI periods, a 2-min stimulus (blue light) followed immediately by a response-independent shock was added. Response rates during the blue light increased and came to resemble the temporal pattern engendered by a fixed-interval schedule. Subsequent experiments analyzed the factors responsible for responding during the blue stimulus. Removal of the shock at the end of the blue stimulus resulted in lowered rates during the stimulus. After reinstating the shock at the end of the stimulus and recovery of the original pattern of responding, successive removal of the avoidance schedule and the variable-interval schedule did not alter the pattern of responding in blue. However, removal of both schedules, but with the stimulus–shock pairings still in effect, eventually led to a cessation of responding. Avoidance performance was then reestablished and extinguished in the absence of shocks at the end of the blue stimulus, after which shocks again were presented independently of responding at the end of the blue stimulus. This procedure resulted in reestablishing responding that was maintained across the 38 sessions during which the only programmed events in each session were the shocks at the end of the blue stimulus.

In a final experiment, the yellow (avoidance related) and white (VI related) stimuli were removed, and a session consisted of continuous presentation of the blue stimulus. Response-independent shock was presented every 10 minutes. Figure 8 shows cumulative records of final performance under these conditions. Substantial lever pressing is evident. The figure indicates that lever pressing during the blue stimulus in previous conditions of the experiment was not due to termination of the blue stimulus at the moment of shock presentation, and that the previous experience had resulted in performance whereby lever pressing was maintained by occasional response-independent shock presentation. In commenting on these findings, the authors noted that behavior that persists because of occasional shocks might be viewed as ''abnormal.'' They then point out that, ''Since abnormal behavior is a normal occurrence under these experimental conditions, it is the experimental conditions that are abnormal. To the extent that the essential aspects of the experimental conditions can be specified, the abnormal behavior can be understood and controlled'' (Kelleher et al., 1963, p. 516). They follow this insightful view with suggestions for further experimentation that might lead to specification of the essential aspects of the experimental conditions.

The second study in this group (Morse & Kelleher, 1966) reported the development of techniques for the study of schedule-controlled behavior of squirrel monkeys maintained by negative reinforcement. Specifically, Morse and Kelleher arranged a contingency such that responding was only occasionally effective in terminating a stimulus condition during which brief electric shocks were delivered. In their first experiment, three stimulus conditions could occur. In the presence of a pattern of horizontal bars on a stimulus panel, no shocks were delivered (safe stimulus) and responses (lever presses) had no consequences. In the presence of a red stimulus, shocks were scheduled to occur every 20 s, and the 20th response resulted in replacement of the red stimulus with a 30-s presentation of the safe stimulus. In the presence of a white stimulus, shocks were scheduled to occur at regular intervals after 10 min had elapsed. The first response after 10 min resulted in termination of the white stimulus and 30-s presentation of the safe stimulus. The time between shocks after the 10-min FI had lapsed was varied between 1 and 10 s. The stimuli and the associated schedules of shock presentation were termed shock–stimulus complexes. The initial experiment illustrated that schedule-appropriate behavior developed under these conditions, with the FR 20 schedule producing a brief pause followed by a high constant rate, and the FI 10 resulting in the typical FI ''scallop.'' Subsequent experiments showed that response rates under the FI and FR schedules were an inverse function of the frequency of scheduled shock delivery. A final experiment compared responding under a fixed-interval schedule of food presentation to that maintained by a fixed-interval schedule of shock–stimulus-complex termination. Figure 9 shows the results. The similarity in performance is remarkable. Through careful examination and control of parameters, therefore, it was possible to produce essentially identical temporal patterns of performance in behavior maintained by food presentation and by negative reinforcement. These procedures provide the bases, consequently, for powerful analyses of how other variables, for example, drugs, interact with behavior presumably controlled by different motivational conditions.

The next study in the series (Morse, Mead, & Kelleher, 1967) also focused initially on effects of response-independent brief shocks. The researchers had noticed in previous observations with squirrel monkeys that brief electric shocks to the monkey's tail (the monkeys were restrained in a chair) elicited, presumably as an aggressive response, biting and pulling of a chain leash that the monkeys wore to allow safe handling. The leash was hooked to a switch that counted these responses automatically, and the investigators then examined several conditions of shock presentation. Exposure to an alternative schedule in which shock was delivered either according to a fixed-interval 30-s schedule or a fixed-time 60-s schedule resulted in high rates of chain pulling, with almost all shocks delivered from the FI schedule. In 1 of the 3 monkeys, responding was maintained under an FI 30-s schedule alone, and the temporal patterning of leash pulling was similar to that seen under fixed-interval schedules of positive reinforcement. That is, behavior that originally appeared to be simply elicited by shock presentations came, over the course of new experience, to resemble operant behavior.

The final study of the four (Kelleher & Morse, 1968) can be understood as an outgrowth of those just described. Although not designed as such, it is likely that the two studies just described provided just the right history to lead to the experimental choices that were made subsequently. This third set of experiments began as an investigation of punishment. Squirrel monkeys were trained to press a lever under a VI 2-min schedule of food presentation. An FI 10-min schedule of shock

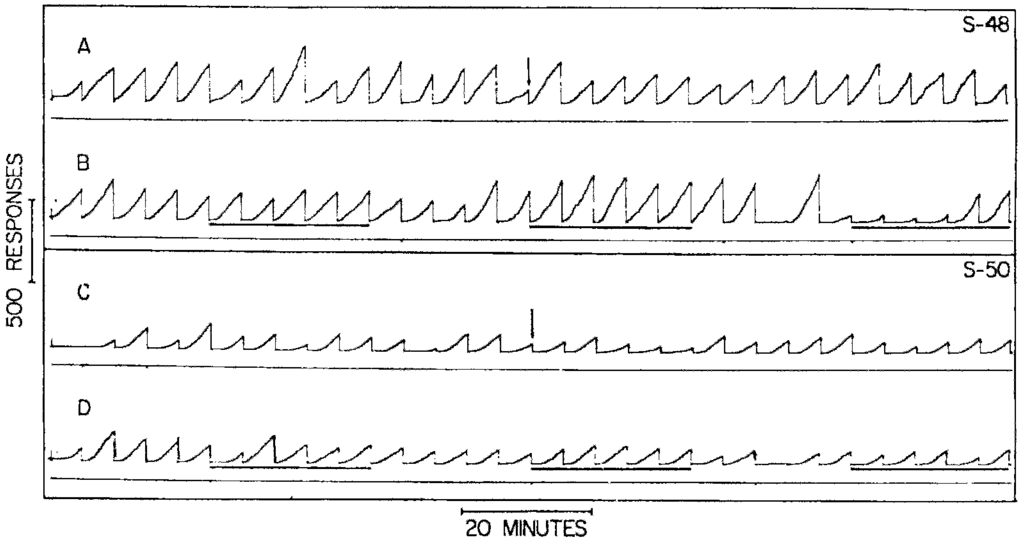

Fig. 9. Cumulative records of lever pressing by squirrel monkeys under FI 5-min schedules of food presentation or termination of a shock–stimulus complex. In Panels A and C the consequence of completing the FI switched from one to the other. In the other two panels (B and D), the bars under records indicate FIs that ended with food presentation. (From Morse & Kelleher, 1966).

presentation was then added, but instead of resulting in lowered rates of responding, the major effect was to produce temporal organization of lever pressing through each fixed interval. Specifically, the constant rate of responding engendered by the VI schedule was changed such that rates were low at the beginning of each FI and then increased as the interval progressed. This unexpected outcome led to several experimental manipulations that eventually revealed remarkable instances of behavioral control. The first manipulation was to add a 1-min period at the end of each 10-min FI during which every lever press resulted in shock. The major effects of that procedure were to accentuate the temporal patterning during the FI and completely suppress responding during the 1-min period. Removing the shock led to a recovery of typical performance under the VI 2-min schedule. The shock was then reintroduced, and temporal patterning again developed.

The next manipulation is one that not many would have made, but it revealed a phenomenon no one would have predicted. The change in procedure was to remove the VI food schedule from the regimen. That is, only schedules of response-dependent shock presentation were left. Figure 10 shows cumulative records sampled across the first 135 sessions of exposure to these conditions. *Lever pressing was maintained throughout under conditions in which the only arranged consequence of pressing was delivery of an electric shock.* This astonishing result testifies to the complexity of behavioral control and the importance of interactions between ongoing behavior and the scheduling of stimuli. Systematic analyses of these amazing results to illuminate their full implications have yet to be conducted. (For interesting follow ups see Galbicka & Platt, 1984, and Laurence, Hineline, & Bersh, 1994).

The experiments on how schedules of noxious stimuli interact with behavior led to two book chapters (Morse & Kelleher, 1970, 1977) in which the importance and implications of studying schedules of noxious stimuli are outlined. The chapters review in some detail the work just summarized, and they also offer insights as to the significance of the work for a general theory of how consequences influence behavior. Consider the following quotations:

> The modification of behavior through reinforcement depends not only upon the occurrence of a certain kind of environmental effect called a reinforcer, but also upon the quantitative properties of the ongoing behavior preceding the event and the schedule under which the event is presented. (1970, p. 139)

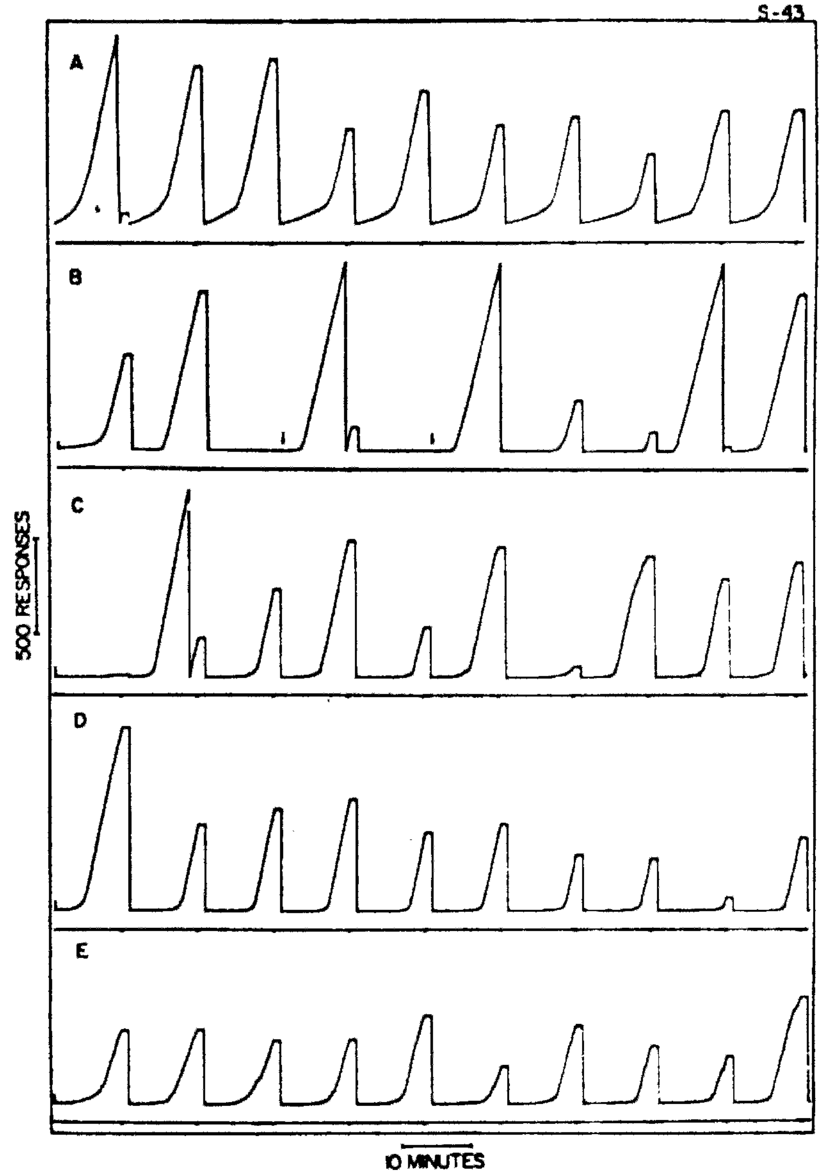

Fig. 10. Cumulative records of lever pressing under schedules of electric shock presentation. An FI 10-min schedule alternated with a 1-min period of FR 1. Record A shows performance in the first session during which a VI 2-min schedule of food presentation was omitted. Records B-E show data from the subsequent 8th, 49th, 98th, and 135th session, respectively. (From Kelleher & Morse, 1968).

The importance of existing behavior in determining subsequent behavior is neglected because of the tendency to shift the focus of the interaction between behavior and environmental events toward the environmental events. A stimulus paired with a reinforcer is said to have become a conditioned reinforcer, but actually it is the behaving subject that has changed, not the stimulus. Similarly, the physical properties of a discriminative stimulus are the same before and after it controls behavior. The effects of environmental effects that maintain behavior depend on what behavior is present. (1970, p. 183).

Identifying an event as a reinforcer or punisher independently of the conditions of use has limited predictive utility. On the other hand,

> prior identification of the suitable conditions that will result in the same behavioral process does provide generality. (1977, p. 177)

> The historical difference between reinforcement and punishment is that a greater range of maintenance conditions have been studied with punishment, which explains why punishment may have appeared to be variable. In actual fact, studies on reinforcement have dealt mostly with restrictive, idealized cases, which may have given the false impression that the effects of known reinforcers are not critically dependent upon conditions under which they operate. (1977, p. 183)

It is remarkable how apt these statements remain.

SERVICE TO BEHAVIOR ANALYSIS

The third domain into which Kelleher's contributions can be placed is in service to the discipline. Roger authored four technical notes in *JEAB* (Gill, Fry, & Kelleher, 1962a, 1962b; Herndon, et al., 1958; Norris & Kelleher, 1958) and two technical articles. One of the latter (Kelleher, Gill, Riddle, & Cook, 1963) outlines procedures that are useful when one employs squirrel monkeys as experimental subjects, and the paper remains an excellent resource. The other (Fry, Kelleher, & Cook, 1960) provides the derivation of and formulae for the mathematical index of curvature that has been, and continues to be, widely used as a measure of temporal patterning of free-operant behavior, especially behavior maintained under fixed-interval schedules.

Interestingly, Kelleher was one of the first to respond in print to the paper by the Brelands (Breland & Breland, 1961) in which ''egregious failures'' of operant contingencies were described anecdotally (Kelleher, 1962). He noted that most of the ''failures'' occurred early in extended chains of behavior, and pointed out that operant behavior is often poorly maintained at the beginning of long chains of behavior. He reported also on his own work with token reinforcement with chimps wherein species-typical behavior also was often observed, but that in his case it did not compete with control by the operant contingencies. The concluding two sentences of this contribution are prescient, and essentially describe the current view (after several decades of mistaken interpretations). They are:

> However, I think that we should conclude that intrusions of ''instinctive behavior'' (like the intrusions of other kinds of competing behavior) are a function of variables which we can discover, specify, and control.
> It is unfortunate that the Brelands have used their impressions to revive the idea that unlearned behavior and conditioned behavior are mutually exclusive. (p. 659)

If only more experimental psychologists had paid attention to these wise words.

As a final indicator of Roger's service and dedication to the development and promotion of an experimental analysis of behavior, I offer a section from the authors' footnote to a publication by Catania and Dobson (1972). It reads as follows: ''We are also indebted to R. T. Kelleher, who rescued an undergraduate laboratory course from cancellation in 1965 with an emergency delivery of pigeons that included Pigeons 3 and 115.'' (The pigeons were used in the reported research.)

Roger Kelleher was a great scientist, and an equally great person. He played a key role in the origin and development of the field we now know as the experimental analysis of behavior. His contributions to that field remain an essential, rich, and still viable legacy.

REFERENCES

Bitterman, M. E., Fedderson, W. R., & Tyler, D. W. (1953). Secondary reinforcement and the discrimination hypothesis. *American Journal of Psychology, 66,* 456–464.

Breland, K., & Breland, M. (1961). The misbehavior of organisms. *American Psychologist, 16,* 681–684.

Bugelski, R. (1956). *The psychology of learning.* New York: Holt, Rinehart, & Winston.

Byrd, L. D. (1971). Responding in the pigeon under chained schedules of food presentation: The repetition of a stimulus during alternate components. *Journal of the Experimental Analysis of Behavior, 16,* 31–38.

Catania, A. C., & Dobson, R. (1972). Concurrent performances: Rate and accuracy of free-operant oddity responding. *Journal of the Experimental Analysis of Behavior, 17,* 25–35.

Fry, W., Kelleher, R. T., & Cook, L. (1960). A mathematical index of performance on fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 3,* 193–199.

Galbicka, G., & Platt, J. R. (1984). Interresponse-time punishment: A basis for shock-maintained behavior. *Journal of the Experimental Analysis of Behavior, 41,* 291–308.

Gill, C. A., Fry, W., & Kelleher, R. T. (1962a). Sound-resistant housing for experimental chambers. *Journal of the Experimental Analysis of Behavior, 5,* 32.

Gill, C. A., Fry, W., & Kelleher, R. T. (1962b). Rack for cumulative-response recorders. *Journal of the Experimental Analysis of Behavior, 5*, 48.

Herndon, J. F., Greenberg, S. M., VanLoon, E. J., Kelleher, R. T., Cook, L., & Davidson, A. (1958). A liquid diet for animals in behavioral studies. *Journal of the Experimental Analysis of Behavior, 1*, 291–292.

Kelleher, R. T. (1955). The effect of randomizing the Cleeton Vocational Interest Inventory items. *Journal of Applied Psychology, 39*, 357.

Kelleher, R. T. (1956a). Discrimination learning as a function of reversal and nonreversal shifts. *Journal of Experimental Psychology, 51*, 379–384.

Kelleher, R. T. (1956b, October 12). Intermittent conditioned reinforcement in chimpanzees. *Science, 124*, 679–680.

Kelleher, R. T. (1957a). A comparison of conditioned and food reinforcement on a fixed-ratio schedule in chimpanzees. *Psychological Newsletter, 8*, 88–93.

Kelleher, R. T. (1957b). Conditioned reinforcement in chimpanzees. *Journal of Comparative and Physiological Psychology, 50*, 571–575.

Kelleher, R. T. (1958a). Stimulus-producing responses in chimpanzees. *Journal of the Experimental Analysis of Behavior, 1*, 87–102.

Kelleher, R. T. (1958b). Fixed-ratio schedules of conditioned reinforcement with chimpanzees. *Journal of the Experimental Analysis of Behavior, 1*, 281–289.

Kelleher, R. T. (1961). Schedules of conditioned reinforcement in experimental extinction. *Journal of the Experimental Analysis of Behavior, 4*, 1–5.

Kelleher, R. T. (1962). Variables and behavior. *American Psychologist, 17*, 659–660.

Kelleher, R. T. (1966a). Chaining and conditioned reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 160–212). New York: Appleton-Century-Crofts.

Kelleher, R. T. (1966b). Conditioned reinforcement in second-order schedules. *Journal of the Experimental Analysis of Behavior, 9*, 475–485.

Kelleher, R. T., & Cook, L. (1959). An analysis of the behavior of rats and monkeys on concurrent fixed-ratio avoidance schedules. *Journal of the Experimental Analysis of Behavior, 2*, 203–211.

Kelleher, R. T., & Fry, W. T. (1962). Stimulus functions in chained fixed-interval schedules. *Journal of the Experimental Analysis of Behavior, 5*, 167–173.

Kelleher, R. T., Fry, W., & Cook, L. (1959). Inter-response time distribution as a function of differential reinforcement of temporally spaced responses. *Journal of the Experimental Analysis of Behavior, 2*, 91–106.

Kelleher, R. T., Fry, W., & Cook, L. (1964). Adjusting fixed-ratio schedule in the squirrel monkey. *Journal of the Experimental Analysis of Behavior, 7*, 69–77.

Kelleher, R. T., Gill, C. A., Riddle, W. C., & Cook, L. (1963). On the use of the squirrel monkey in behavioral and pharmacological experiments. *Journal of the Experimental Analysis of Behavior, 6*, 249–252.

Kelleher, R. T., & Gollub, L. R. (1962). A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior, 5*, 543–597.

Kelleher, R. T., & Morse, W. H. (1968). Schedules using noxious stimuli. III. Responding maintained with response-produced electric shocks. *Journal of the Experimental Analysis of Behavior, 11*, 819–838.

Kelleher, R. T., Riddle, W. C., & Cook, L. (1962). Observing responses in pigeons. *Journal of the Experimental Analysis of Behavior, 5*, 3–13.

Kelleher, R. T., Riddle, W. C., & Cook, L. (1963). Persistent behavior maintained by unavoidable shocks. *Journal of the Experimental Analysis of Behavior, 6*, 507–517.

Laurence, M. T., Hineline, P. N., & Bersh, P. J. (1994). The puzzle of responding maintained by response-contingent shock. *Journal of the Experimental Analysis of Behavior, 61*, 135–153.

Marr, M. J. (1979). Second-order schedules and the generation of unitary response sequences. In M. D. Zeiler, & P. Harzem (Eds.), *Advances in the analysis of behaviour: Vol. 1. Reinforcement and the organisation of behaviour* (pp. 223–260). Chichester, England: Wiley.

Morse, W. H., & Kelleher, R. T. (1966). Schedules using noxious stimuli. I. Multiple fixed-ratio and fixed-interval termination of schedule complexes. *Journal of the Experimental Analysis of Behavior, 9*, 267–290.

Morse, W. H., & Kelleher, R. T. (1970). Schedules as fundamental determinants of behavior. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules* (pp. 139–185). New York: Appleton-Century-Crofts.

Morse, W. H., & Kelleher, R. T. (1977). Determinants of reinforcement and punishment. In W. K. Honig, & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 174–200). Englewood Cliffs, NJ: Prentice-Hall.

Morse, W. H., Mead, R. N., & Kelleher, R. T. (1967, July 14). Modulation of elicited behavior by a fixed-interval schedule of electric shock presentation. *Science, 157*, 215–217.

Norris, J., & Kelleher, R. (1958). Spark suppression. *Journal of the Experimental Analysis of Behavior, 1*, 30.

Sidman, M. (1953). Two temporal parameters of the maintenance of avoidance behavior by the white rat. *Journal of Comparative and Physiological Psychology, 46*, 253–261.

Wyckoff, L. B. Jr (1952). The role of observing responses in discrimination learning: Part I. *Psychological Review, 59*, 431–442.

Wyckoff, L. B., Jr. Sidowski, J., & Chambliss, D. J. (1958). An experimental study of the relationship between secondary reinforcing and cue effects of a stimulus. *Journal of Comparative and Physiological Psychology, 51*, 103–109.

Zeiler, M. D. (1970). Time limits for completing fixed ratios. *Journal of the Experimental Analysis of Behavior, 14*, 275–286.

Zeiler, M. D. (1972). Time limits for completing fixed ratios, II: Stimulus specificity. *Journal of the Experimental Analysis of Behavior, 18*, 243–251.