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ON THE APPLIED USE OF PROGRESSIVE-RATIO SCHEDULES OF REINFORCEMENT

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Examination of responding under various schedule arrangements is a core component of many analyses of operant behavior. Much of the pioneering work in applied behavior analysis was bred from laboratory research involving the exposure of nonhuman subjects to a variety of schedule arrangements. For example, Reynolds (1961) described a multiple-schedule arrangement in which one component consisted of reinforcement for not responding for a specific period of time (i.e., differential reinforcement of other behavior [DRO]). Exposure to the DRO schedule resulted in generally low rates of responding. Since the initial publication of the basic DRO schedule arrangement, DRO procedures have been frequently employed in the treatment of destructive behavior (e.g., Cowdery, Iwata, & Pace, 1990; Mazaleski, Iwata, Vollmer, Zarcone, & Smith, 1993).

Hodos (1961) described a schedule arrangement in which the requirement to access reinforcement increased on a trial-by-trial basis within the course of a single session. That is, the subject would initially emit a predetermined number of responses before reinforcement delivery (e.g., 20 responses). Following reinforcer delivery, the subsequent response requirement would increase by some increment (e.g., another 10 responses; referred to as a step size) such that in the next trial the subject would be required to complete more responses than in previous trials (e.g., 30 responses before reinforcer delivery, 40 responses before reinforcer delivery). Within-session changes in response requirements in this pattern constitute a progressive-ratio (PR) schedule of reinforcement. (It should be noted that increasing response requirements over successive sessions, e.g., DeLeon, Iwata, Goh, & Worsdell, 1997; Tustin, 1994; has been conceptualized as a form of PR schedule arrangement by some, e.g., Cooper, Heron, & Heward, 2007. For the purpose of the current discussion, PR schedules will be conceptualized as those schedules that increase during the course of a single session.)

The primary clinical application of PR schedules involves assessment and quantification of differential reinforcer efficacy, which has sometimes been referred to as *reinforcer potency* (i.e., the ability of a reinforcer to maintain behavior; Baron, Mikorski, & Schlund, 1992; Hodos & Kalman, 1963; Johnson & Bickel, 2006). The assessment of reinforcer potency using PR schedules is commonly achieved through a comparison of relative break points (also referred to as breaking points). A break point is usually characterized as the last reinforced PR requirement that is completed. To illustrate, suppose a PR schedule were arranged with a step size of five responses. If a participant completed five trials and emitted 25 responses during the last trial before responding ceased with Stimulus A and completed eight trials and emitted 40 responses during the last trial with Stimulus B before responding ceased, one would conclude that Stimulus B was a more potent reinforcer than Stimulus A because Stimulus B had a higher break point. That is,

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Stimulus B supported more responding as the schedule requirements increased.

In addition to the use of break points as a measure of reinforcer efficacy, PR schedules are also characterized by the omission of a terminal schedule value. That is, PR schedule requirements typically increase throughout the course of a session until responding stops for a period of time (e.g., 5 min) or until a predetermined duration of the observation has been reached (a session cap). Thus, total response output (as opposed to response rate) and break-point values are the primary measures of interest when evaluating behavior with PR schedules.

Previous Applied Examinations of PR Schedules

Tustin (1994) and DeLeon et al. (1997) conducted initial examinations of responding across schedule requirements that increased in a progressive fashion across successive observations (i.e., a progression of successive fixed-ratio [FR] requirements). Based on this work, Roane, Lerman, and Vorndran (2001) conducted an analysis examining the utility of PR schedules in applied settings. Specifically, Roane et al. evaluated the reinforcing efficacy of different stimuli as reinforcers for responding on PR schedules. Initially, a preference assessment (based on Fisher et al., 1992) identified two stimuli that were chosen on an equivalent number of presentations. These stimuli were then evaluated as reinforcers under PR schedules that were presented in a single-operant arrangement. For all participants, one stimulus was associated with more responding under PR schedules relative to the other. These results suggested that although the two stimuli appeared to be equally effective reinforcers at relatively low response requirements (i.e., selection responses in the preference assessment and relatively low PR requirements), they were associated with differentiated levels of responding under increasing response requirements. Thus, the differential effectiveness of the stimuli as reinforcers became apparent only as the response requirements increased.

To date, the clinical utility of PR schedules has received only limited attention in applied research. In addition to the Roane et al. (2001) study described above, only three other papers published in the *Journal of Applied Behavior Analysis* (*JABA*) have evaluated clinical applications of PR schedules. DeLeon, Fisher, Herman, and Crosland (2000) used PR schedules to increase the response requirements for aberrant behavior such that responding was eventually biased toward a concurrently available alternative response. Roane, Call, and Falcomata (2005) and Kodak, Lerman, and Call (2007) used PR schedules to assess responding under situations in which reinforcers were or were not freely available outside the experimental setting.

Despite the relatively limited presentation of PR schedules in applied investigations, the extant literature suggests at least three important research topics on PR schedules that have relevance to the field of applied behavior analysis. These include procedural considerations for the arrangement of PR schedules, the use of PR schedules to bridge basic and applied research topics, and the clinical use of PR schedules to develop therapeutic programs. The set of studies that follows in this issue of *JABA* consists of unsolicited research on the use of PR schedules in applied settings, each of which corresponds to at least one of the aforementioned areas. In the following sections, previous and current studies will be integrated into a discussion of each of these areas, and directions of future research will be presented.

Procedural Considerations for the Arrangement of PR Schedules

There are several methodological details to be considered when developing PR schedules for use in applied settings. Such factors include determining an appropriate algorithm for the progression of schedule requirements (e.g., increasing additively or geometrically), session-termination criteria (e.g., after cessation of responding for a period of time or after a total amount of time has elapsed), the type of target response to use (e.g., a relatively simple or a more complex operant), and the amount of reinforcement delivered throughout the analysis. Each of these variables has been inconsistently manipulated across the existing applied studies. For example, Roane et al. (2001) used a variety of PR step-size manipulations that varied on a case-by-case basis (either increasing arithmetically or geometrically within participants), yet participants were always exposed to each schedule value twice before the response requirement progressed. By contrast, Roane et al. (2005) used PR schedules that progressed arithmetically, with no repetition of previous schedule requirements. DeLeon et al. (2000) included PR step sizes that progressed geometrically, but only after participants had earned three reinforcers at a particular schedule value. Finally, Kodak et al. (2007) included response requirements that progressed arithmetically by two responses, but the PR requirements did not reset to the initial value at the beginning of each subsequent session. It is possible that such disparities across studies could influence the obtained results.

The study by Glover, Roane, Kadey, and Grow (2008) exemplifies research that evaluates methodological considerations in the development of PR schedules. The majority of applied research has evaluated PR schedules in a single-operant arrangement (i.e., only one PR schedule operating at a time). Glover et al. assessed the extent to which PR schedules presented under single or concurrent arrangements (i.e., two independently operating PR schedules presented simultaneously) would produce differential outcomes across stimuli. The resulting data suggested that similar break points were obtained when PR schedules were arranged either singly or concurrently. This is a potentially important finding because prior research using FR 1 schedules in single and concurrent arrangements has generally produced disparate results (e.g., Fisher & Mazur, 1997; Roscoe, Iwata, & Kahng, 1999). Thus, if the findings of the Glover et al. investigation are robust and can be replicated in subsequent investigations, they suggest that PR schedules produce consistent and reliable estimates of reinforcer potency across contexts.

Using PR Schedules to Bridge Basic and Applied Research

In the extant applied literature, PR schedules have been used as components of experiments that have replicated both basic and applied research and have helped to determine the generality of the hypothesized relation between response requirements and the relative efficacy or potency of reinforcers. For example, Roane et al. (2005) and Kodak et al. (2007) arranged experimental procedures to approximate two types of economic subsystems (open and closed economies). In both cases, PR schedules were used to evaluate responding when participants either did or did not receive supplemental (postsession) access to highly preferred reinforcers. Similar to the results of basic studies on open and closed economies (e.g., Hursh, 1980), both of these applied studies suggested that higher rates of responding were associated with conditions in which participants did not receive supplemental access to preferred reinforcers (i.e., a closed economy). These outcomes represent the translational use of PR schedules in that these studies were the first to conduct within-subject comparisons of responding under open and closed economies in an applied context.

PR schedules also have been used to replicate previous applied research. As noted previously, Roane et al. (2001) used PR schedules to replicate the earlier findings of DeLeon et al. (1997) and Tustin (1994) in demonstrating that preference for reinforcers varied as response requirements increased. In a similar sense, three of the studies in the current issue of *JABA* (Francisco, Borrero, & Sy, 2008; Glover et al., 2008; Penrod, Wallace, & Dyer, 2008) attempted to replicate the findings of Roscoe et al. (1999) by evaluating the extent to which low-preference stimuli (i.e., those not often selected in a preference assessment) functioned as positive reinforcers under PR schedules. Experiment 2 of the Glover et al. investigation suggested that low-preference stimuli were not as effective as highly preferred stimuli at supporting responding under PR schedules. By contrast, both Penrod et al. and Francisco et al. showed that low-preference stimuli often functioned as effective reinforcers under PR schedules.

Clinical Use of PR Schedules in Therapeutic Program Development

Each of the existing studies has some clinical relevance to therapeutic program development. Most notably, DeLeon et al. (2000) incorporated the use of PR schedules directly in the development of a treatment of destructive behavior. Initially, DeLeon et al. observed a bias toward aggression when aggression and communication were reinforced on concurrent FR 1 schedules. Next, aggression was reinforced on a PR schedule (ranging from 1 to 20 responses per reinforcer delivery) while communication continued to be reinforced on an FR 1 schedule. Initially, the bias toward aggression persisted as the schedule of reinforcement for that response increased from 1 to 10 responses; however, when the participant had to display 20 aggressive responses to access reinforcement (relative to one communicative response), response allocation began to favor communication. The resulting schedule differences were incorporated into a successful treatment in which communication and aggression were reinforced on concurrent but unequal FR schedules.

Roane et al. (2001) also used the results from PR assessments to inform treatment development for 3 individuals who displayed destructive behavior. As noted above, the results of PR schedule evaluations for all participants revealed that one stimulus was associated with higher break points than another stimulus. In the treatment phase of the investigation, Roane et al. evaluated the stimuli as separate components of three reinforcement-based treatments. Across all participants, the stimulus associated with more responding under PR schedules was generally associated with greater reductions in destructive behavior during treatment, suggesting that the stimuli were differentially effective reinforcers when incorporated into reinforcement-based interventions.

The research by Trosclair-Lasserre, Lerman, Call, Addison, and Kodak (2008) extends the use of PR schedules in therapeutic program development. These authors employed PR schedules to assess the relative efficacy of different durations of positive reinforcers (e.g., 10 s or 120 s). A potential clinical implication of this investigation is that magnitudes associated with more responding under PR schedules may also be associated with greater treatment effects.

The investigation by Jerome and Sturmey (2008) is a unique extension on the application of PR schedules to program development. The participants in the Jerome and Sturmey investigation initially identified preferred and nonpreferred direct-care staff through a preference assessment (based on Fisher et al., 1992). In a subsequent analysis, participants completed tasks that were reinforced on PR schedules by providing contingent interactions with either preferred or nonpreferred staff. All participants obtained higher break points when responding resulted in access to highly preferred staff. A potentially important clinical implication of this investigation is that the efficacy of some reinforcement-based interventions may be affected by the reinforcement value of those who implement the program, which may be accurately assessed using PR schedules.

Implications and Suggestions for Future Research

Each of the areas discussed above present directions of future investigation. There are several areas related to the arrangement of PR schedules that could be considered for future investigation. As discussed previously, there is currently no agreed-upon algorithm for determining the initial schedule value or step-size progression in applied PR schedule arrangements. In addition, it is possible that the type of target response used might affect responding under PR schedules. In previous research and in the investigations in the current issue of *JABA*, the target responses have ranged from simple (e.g., pressing a button; Trosclair-Lasserre et al., 2008) to more complex operants (e.g., academic skills; Kodak et al., 2007). It is unknown how differences in response topography might interact with increases in response requirements to affect participant responding, but it is reasonable to assume that more complex (effortful) responses would be associated with decreased levels of responding as requirements increase (Friman & Poling, 1995).

Another area of future research involves the potential interaction between the increased response requirements that are inherent in PR schedules and the duration of reinforcer delivery following completion of a PR requirement. Several recent applied investigations have suggested that the relative price of a reinforcer may affect response allocation for that reinforcer (e.g., Borrero, Francisco, Haberline, Ross, & Sran, 2007; Roane, Falcomata, & Fisher, 2007). Generally speaking, there is an inverse relation between price and responding such that as the price of a reinforcer increases, responding for that reinforcer decreases. Under a PR schedule with a constant reinforcer duration (e.g., 20 s), the price of a reinforcer changes rather quickly (i.e., response requirements increase while reinforcer duration is constant). It is possible that higher break points might be obtained under situations in which reinforcer duration increases proportional to increases in the response requirement relative to those in which reinforcer duration is constant. The results obtained by Trosclair-Lasserre et al. (2008) allude to this possibility, in that their participants demonstrated more responding for some reinforcer magnitudes than for others.

Almost any previous study that has examined variables that alter the effectiveness of positive reinforcement could be replicated using PR schedules. Of interest would be the extent to which preferences for different types, duration, or amounts of reinforcement vary across increasing schedule requirements (e.g., Trosclair-Lasserre et al., 2008). Given the use of functional analyses to identify the variables that maintain problem behavior, future research also could examine the reinforcing efficacy of functional and so-called arbitrary reinforcers when both are presented contingent on the completion of various PR requirements. Previous research has shown that arbitrary reinforcers (i.e., highly preferred stimuli that do not maintain behavior) may be equally or more effective as treatment agents than functional reinforcers under relatively low-effort response requirements (i.e., noncontingent access; Fischer, Iwata, & Mazaleski, 1997; Fisher, O'Connor, Kurtz, DeLeon, & Gotjen, 2000; Hanley, Piazza, & Fisher, 1997). However, the comparative reinforcing efficacy of arbitrary and functional reinforcers under PR response requirements remains unknown. Likewise, situations involving destructive behavior maintained by multiple reinforcement contingencies (e.g., Lindauer, Zarcone, Richman, & Schroeder, 2002) may be applicable for evaluation with PR schedules. Under such circumstances, PR schedules could be used to compare the reinforcing efficacy of distinct functional (or arbitrary) reinforcers, which might suggest a differential response to treatment for those reinforcers.

Although PR schedules are commonly used in psychopharmacological research to evaluate the reinforcing efficacy of different drugs or dosages (see Stafford, LeSage, & Glowa, 1998, for a review), such procedures have yet to be applied to the study the therapeutic effects of pharmacological interventions in applied settings. A number of recent contributions to *JABA* by Northup and colleagues (Gulley & Northup, 1997; Northup et al., 1999; Northup, Fusilier, Swanson, Roane, & Borrero, 1997; Northup, Jones, et al., 1997) and others (Kelley, Fisher, Lomas, & Sanders, 2006; Yoo et al., 2003) have focused on the use of medications to treat destructive behavior problems. The use of PR schedules could augment such research. To illustrate, both methylphenidate and risperidone (and their related derivatives) are commonly used pharmacological interventions for behavior disorders. Incidentally, these medications are also associated with specific side effects (decrease in appetite and weight gain, respectively) that could affect the reinforcing efficacy of certain stimuli (e.g., food). For individuals undergoing medication evaluations, PR schedules could be used to assess response to treatment (e.g., maintenance of responding across dosages or medications) or the role of different dosages or medications on the efficacy of specific stimuli (e.g., food, social interaction; LaRue et al., 2008) as positive reinforcers.

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