4-2007

Fluency in Pigeons: The Effects of Response Rate on Learning

Matthew L. Porritt
Western Michigan University

Recommended Citation

Porritt, Matthew L., "Fluency in Pigeons: The Effects of Response Rate on Learning" (2007). *Dissertations*. 907.
https://scholarworks.wmich.edu/dissertations/907

FLUENCY IN PIGEONS: THE EFFECTS OF RESPONSE RATE ON LEARNING

by

Matthew L. Porritt

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
Department of Psychology

Western Michigan University
Kalamazoo, Michigan
April 2007

FLUENCY IN PIGEONS: THE EFFECTS OF RESPONSE RATE ON LEARNING

Matthew L. Porritt, Ph.D.

Western Michigan University, 2007

Instructional procedures that build high response rates are purported to have significant benefits over procedures that do not focus on fast responding (Binder, 1996). However, much of the research exploring rate-building procedures is confounded by two variables: rate of reinforcement and number of exposures (Doughty, Chase, & O’Shields, 2004). In six experiments, the present study examined the effects of three variables, rate of reinforcement, number of exposures, and rate of responding, on learning under rate-building procedures in pigeons. In Experiment 1, rate-building produced significantly better learning outcomes when compared to a rate-controlled condition with number of exposures held constant. In Experiments 2 and 3, significantly higher rates of reinforcement during rate-building conditions failed to produce differences in learning outcomes when response rates and number of exposures was held constant. In Experiment 4 rate-building produced significantly better learning outcomes, despite holding rate of reinforcement and number of exposures constant across rate-building and rate-controlled conditions. In Experiment 5 the arrangement of rate-controlled experimental procedures was changed to demonstrate the effect of decreasing latencies between responses within a trial (chain of responses) while controlling trial spacing. When rate-building was arranged within each trial, learning outcomes were significantly better than when rate of responding was controlled within and between trials. Experiment 6 demonstrated that the effect of rate-controlled conditions was due to decreased response rates and not an artifact of procedural manipulations. Overall, the results suggest that training responses to high rates enhances learning and support the use of rate-building procedures.

UMI Number: 3263336

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

ACKNOWLEDGMENTS

To begin, I would like to thank my wife, Melissa Porritt, for her love and support even when it meant sacrificing me to the pigeons each weekend and most holidays. I would also like to thank Dr. Alan Poling for wit and candor that made my graduate education a much cooler hell than it would have been. I also owe a great debt to my research assistants: Karen Van Wagner, Adam Rapp, Claus Globig, Trista McClelland, Kelly Stone, and Alex Birchmeier. Thank you also to my committee: Drs. Eric Fox, Brad Huitema, and Kent Johnson.

Finally, I would like to thank my parents, Tom and Ingrid Porritt, for the love and support they have provided throughout my life.

Matthew L. Porritt

TABLE OF CONTENTS

CHAPTER

Table of Contents—continued

CHAPTER

Table of Contents—continued

CHAPTER

APPENDICES

LIST OF TABLES

LIST OF FIGURES

List of Figures—continued

CHAPTER I

INTRODUCTION

The Need for Evidence-based Educational Methods

Our society is undertaking a more critical evaluation of how it educates and cares for its members; this is due to a recent emphasis on accountability. “The twenty-first century has introduced an era of accountability, with a demand for advocates of important social cultural activities to ‘prove’ the ‘facts’ they promote, so that decisions affecting the public will lead to consistent, socially valuable goals” (Moran, 2004, p. 3).

The public interest in accountability is reflected in many areas of social concerns such as medicine, psychology, and education. Evidence-based medicine is a type of medical practice that follows guidelines answering the questions, "Are these medical procedures proven to promote health?" and "Is it a fact that this is the most effective and efficient treatment for this patient?" Within clinical psychology, empirically supported treatments are gaining favor. Psychologists are more often asking the question "Is this therapy proven to be effective and efficient?" Asking such questions of medicine and psychological treatment are important so that we are accountable for the time and money spent to address important issues. Similarly, accountability within education is on the rise.

To adopt evidence-based educational practices is to ask the question, "Are the educational practices used in schools actually effective and efficient?" This question rang true with the voting public in 2000 when George W. Bush ran for president on an educational platform of accountability. Exit polls from this election ranked education as the second most important issue, behind the economy and jobs (Cable News Network, 2000). In a bi-partisan effort Congress and President Bush drafted and passed the No Child Left Behind act (NCLB) in late 2001; it was quickly signed into law by President Bush on January 8, 2002.

NCLB requires accountability through the demonstration of "adequate yearly progress" (AYP). What counts as AYP is determined at the state level—usually by standardized testing. For example, a state may require that a majority of grade levels within a school show progress in the percentage of students that pass a standardized test. If AYP is not met, schools may lose funding. This arranges a definite financial penalty for schools if they do not make quantitative gains in educational quality. Therefore, schools are accountable for selecting and enforcing practices that lead to educational improvement.

Although a child's development within the classroom depends on many factors, instructional strategies employed by the classroom leaders are major determinants of educational success—specifically the types of educational development measured within standardized tests used for measuring AYP in many states. The US Department of Education has established the Institute of Education Studies (IES), which attempts to evaluate research into various educational practices and provide a clearing house of "scientifically proven" practices (currently available at http://www.w-w-c.org).

In order to be deemed a "scientifically proven" educational practice, a scientifically valid research study must have been conducted with results favorable to the given practice. Additionally, a study that is considered "scientifically valid" by the IES must adhere to certain constraints. The IES requires that a scientifically valid study be conducted with comparisons made between large randomized groups of students. However, sound research into effective instructional techniques and educational methods is not solely limited to between-groups designs. In particular, research conducted within Applied Behavior Analysis often demonstrates the effectiveness of interventions by utilizing within-subject or within-group designs. These designs (such as multiple baseline, reversal, and changing criterion), when used correctly, leave little room for doubt reporting the effects of the independent variable on the dependent variable in question. Generalization of results is demonstrated not by conducting large group studies, but through successful replication of results in different contexts (Poling, Methot, & LeSage, 1995). It may be that by ignoring any study that is not conducted using a between-groups design the government is overlooking instructional techniques that may be valuable to education.

Rate of Responding in Instruction

One instructional method repeatedly studied by behavior analysts is rate-building. This procedure typically involves building fast, accurate, and repeated performance of learned skills, usually to a defined criterion (Doughty, Chase, & O’Shields, 2004). Criterion-level performance is referred to as fluency and a great deal of research literature has been devoted to the enhanced effects of training behaviors to fluency. The application of behavior analysis to education is growing and fluency makes up a great deal of this application, particularly within the specific application of Precision Teaching (PT) (Doughty et al., 2004). Much of the research into rate-building within education has been conducted in applied settings by Precision Teachers, and they are the most prominent advocates of training skills to fluency.

Fluency is defied by Binder (1996) as “the fluid combination of accuracy plus speed that characterizes competent performance (p. 164).” It was empirically described by Haughton in 1980 by the acronym REAPS, which refers to the effects of rate-building procedures on learned skills: enhanced Retention, Endurance, and Application.

Retention refers to the maintenance of a learned skill at testing after some time has elapsed since training. Responses trained to fluency retain lower latencies and higher accuracy after a period of time has passed without the response occurring. Endurance refers to engaging in a trained behavior for extended periods of time while maintaining high accuracy and low latencies. Endurance also includes stability, where performance endures despite environmental distracters, such as noises or other changes in stimuli.

Application is the performance of trained skills in the presence of other, new, or compound stimuli that have not been specifically trained to control emission of the behavior. The new stimuli can be very different from the stimuli used during training and still control performance when appropriate. For example, if a student learns to determine the area of a rectangle in the classroom, she or he would then demonstrate application by performing the skill at home.

A fourth purported benefit of fluent performance is enhanced adduction. When confronted with novel stimuli a student displays adduction by combining skills in novel ways to respond appropriately. This combination of skills results in a response which is considered a composite response composed of component responses. The composite response is more likely to occur if each component response is trained to fluency.

Fluency instructors try to produce sprints of high rate responding rather than slowly-paced or controlled opportunities to respond. Thus, progress through a curriculum is based on not just accuracy but accuracy plus speed (Péladeau, Forget, & Gagné, 2003). It is the assertion of Precision Teachers that latency, or rate, measures provide especially sensitive indicators of response strength and that the traditional practice of measuring accuracy only does not properly measure performance levels (Binder, 1996). The notion of measuring rate of responding rather than accuracy began with the work of Ogden Lindsley, who worked with B. F. Skinner in his human operant laboratory in the 1950s and early 1960s. It is here where the behavioral principles developed by Skinner with rats and pigeons were extended to human behaviors. Soon Lindsley began working with people who displayed behaviors which were developmentally delayed and it is from this work that PT evolved (Binder, 1996).

To facilitate rate-building, Precision Teachers arrange “free-operant” procedures, where the responder is allowed to respond as fast as he or she would like without having to wait for the next opportunity to respond, as occurs under discrete-trial procedures. For example, instead of an instructor presenting a series of simple math problems in which one is presented, the instructor waits for an answer, then delivers feedback before asking a second, in a free-operant procedure the student would be presented with a sheet of several math problems which he or she can then answer as fast as they like without waiting for the instructor to present the next trial. Often, however, Precision Teachers train skills to 60-100% accuracy before moving to free-operant procedures by fading out prompts and feedback but still counting response opportunities (Binder, 1996).

Precision Teachers also use brief timings to increase fluency, usually one minute. Lindsley originally favored recording behaviors over extended periods of time as they did in the human operant laboratory, but he soon found that students who were not fluent in the skills performed poorly and were easily distracted during these longer intervals of performance, and that students disliked this type of practice (Binder, 1996). Precision Teachers now use the one-minute timing consistently across many skills and curricula. Also incorporated with one-minute timings is a significant manipulation in motivating operations (Laraway, Snycerski, Michael, & Poling, 2003). Binder describes PT sessions as resembling a gym more than a classroom. Precision Teachers provide coaching and cheering described as energetic “hustling.” By providing such antecedent stimuli and enthusiastic social consequences, Precision Teachers can highly motivate students and engender the higher response rates needed for fluency. Precision Teachers are continually engaged in training responses to different levels of performance and using different learning arrangements to determine which speeds and arrangements of learning will engender greatest fluency for that particular skill. This process is referred to as setting and defining fluency aims.

Binder describes Precision Teaching and its emphasis on fluency as a paradigm in the Kuhnian sense, in that it “attracts an enduring group of adherents” and is “sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve (p. 165).” If this is true, Precision Teaching should redirect instructional design and education research to focus on fluency. It is Binder’s belief that we are in the beginning of this new paradigm. Unfortunately, when compared to the body of instructional design and education research, research into rate-building procedures is limited to a small corner of behavior analysis. This is due in part to the trend during the early years of PT towards not pursuing publication in academic journals. Lindsley believed that publishing in journals would not affect the professional behavior of educators. The response effort necessary to produce publications was not justified in the view of Lindsley and other early precision teachers (Binder, 1996). Instead, precision teachers would gather at conferences and other meetings and share data graphed on standard celleration charts—a specialized chart developed to display rates of responding. Regardless of the intent, the failure of Precision Teachers to publish their findings regularly within education journals appears to have limited the influence of their findings regarding fluency (Binder, 1996). Several studies have appeared, however, and they are summarized in the following section.

CHAPTER II

REVIEW OF RELATED LITERATURE

Rate-building and Fluent Performance

Peladeau et al. (2003) allowed instructors of 190 college students to provide class points for practicing questions taken from the class subject matters (quantitative methods) as arranged by a computer program. Students were matched by grade point average and aptitude test scores and formed into three equivalent groups. The first group practiced the questions until they achieved mastery defined as stable accuracy at or above 85% correct. The second group, the overlearning group, practiced for five weeks past mastery and was instructed to focus on the accuracy of their responses. The third group, the fluency group, practiced for the same number of trials as their matched pair in the overlearning group, but was instructed to focus on speed of responding rather than accuracy. On retention tests and tests during training, the fluency group performed significantly faster than the overlearning group. The fluency group also displayed less accurate performance than the overlearning group, but this difference was not statistically significant. Both the overlearning and fluency group performed better on all measures than the mastery only group.

Berquam (1981) studied the effects of rate-building in 34 third-grade students. One group of students was trained to fluency on a paired associates task (nonsense syllable – write number) and a second group was trained slowly on the same task, but with 60% more trials. The fluency group exhibited lower latencies and higher accuracies during training and better performance was retained after a two-week retention interval. Additionally, when the initially slow responders were trained to fluency during retention tests, performance achieved the high levels of the other group. However, it is important to note that this research did not control for performance histories.

Haughton (1972) recorded the incorrect and correct response rates of elementary students writing single digits. He found that only students with rates around 100 digits per minute subsequently reached rates of 50 to 60 per minute on simple arithmetic tasks. Further, students who achieved rates of 40 to 50 simple arithmetic tasks per minute were able to progress more smoothly to higher math skills. Orgel (1984) found that college students who produced rates of 50 or more per minute of correct responses on calculus flash cards did nearly twice as well on a 6-week retention test than peers who had lower rates of responding.

Binder (1987, as cited in Johnson and Layng, 2002) trained subjects to associate Arabic numerals with Hebrew characters. When subjects were trained for many trials after an accuracy but not speed criterion was reached, he tested their ability to add Hebrew characters in the presence of a distracter (random spoken numbers). The distracter completely disrupted performance. But when Binder subsequently trained the subjects to a fluency criterion, they were able to perform expertly without disruption in the presence of the distracter.

Makepeace (1998) conducted three experiments in which 18 adult subjects performed matching-to-sample trials in each of three conditions: accuracy, overlearning, and overlearning plus speed. During the accuracy condition, subjects had significantly fewer trials than in the other two conditions. In the overlearning plus speed condition, subjects were allowed to respond significantly faster than in the overlearning only condition, but the subjects were allowed the same number of trials in each these two conditions. Subjects were then tested on their ability to generalize and produce co-adductions after a 30-min distraction period. Although the overlearning conditions resulted in improved performance, there was not a statistically significant difference between the two.

In 2004, Doughty et al. conducted a literature review to examine whether or not evidence exists that building rates beyond accuracy or mastery criteria results in fluency or increased performance. The reviewers also wanted to clarify the behavioral mechanisms that might support the contention that high response rates alone produce fluency. After reviewing 48 articles, the reviewers found that empirical research examining rate-building and fluent performance is mainly confounded by two variables: rate of reinforcement and number of trials. As these variables are not systematically controlled across conditions in rate-building studies we should be hesitant to reach any conclusions about the purported benefits of this procedure solely due to increased rates of responding.

Of the 48 studies reviewed by Doughty et al. only three controlled for rate of reinforcement and number of trials (Evans, Mercer, & Evans, 1983; Evans & Evans, 1985; Shirley & Pennypacker, 1994). Evans, Mercer, and Evans (1983) had different groups of subjects practice a consonant-vowel-consonant trigram recognition task to 40, 60, or 80 responses per minute. The 80 responses per minute group was trained first then the 40 and 60 groups were trained to their specific rate criteria. After rate criteria were reached, the 40 and 60 groups were allowed to practice slowly until they reached the same number of trials as the 80 group. Praise was delivered after each one-minute timing so reinforcement rate was equivalent across groups. Evans and Evans (1985) replicated this experiment with 60, 90, or 120 responses per minute groups. In the first experiment, the 80 responses per minute group did the best on post tests and the 60 responses per minute group did the worst. In the replication the 90 responses per minute group demonstrated the highest accuracy on post tests and the 120 responses per minute group did the worst. These studies, however, did not assess all of the purported characteristics of fluent performance (retention, endurance).

Shirley and Pennypacker (1994) trained two subjects each on two spelling lists. The first list was trained to a rate and accuracy criterion, the second was trained to an accuracy only criterion. The number of trial presentations was equivalent for each list. The researchers found a small difference in retention in favor of the rate-trained list, but only in one of the two subjects. The authors conceded there were some inconsistencies in the performances, and they speculated that training to higher rates would have produced larger, more consistent effects.

The mixed or unfavorable results from the three studies which have controlled for reinforcement rate, response rate, and number of trials casts doubt on the PT researcher’s assertion that rate-building alone and not higher rates of reinforcement or increased trials leads to fluent performance as demonstrated in the rest of the research. At this point it will be helpful to review each of the three mentioned variables and their effects on learning and performance as demonstrated in the literature.

Variables of Interest

Number of Trial Presentations

Overlearning is defined as further study past one perfect trial (Roher, Taylor, Pashler, Wixted, & Cepeda, 2004). When a learner uses an overlearning strategy, he or she has participated in overlearning, regardless if learning occurs. Overlearning procedures are widely advocated within education and are usually described as a means of boosting long-term retention. In one often-cited study (Krueger, 1929), participants completed learning trials with a list of words in one of two training groups. The overlearning group received twice the number of trials as the accuracy only group. When groups were tested at retention intervals of 1 to 28 days, the overlearning group had significantly better recall. These results have been replicated many times. In a meta-analysis by Driskell, Willis, and Cooper (1992), a moderate Cohen's D effect size (0.753) was attributed to overlearning on retention measures. Roher et al. (2004) pointed out that the research literature on overlearning rarely tests more than one retention interval and the retention intervals tested are usually within one week of training. Roher et al. then conducted an experiment testing overlearning repeatedly at longer retention intervals. In two studies, Roher et al. trained subjects on country-city pairs and word-definition paired associates. In the first experiment, the low group trained for 5 test-feedback trials while the high group trained for 20. In the second experiment the low group trained 20 word-definition pairs and the high group trained 10 pairs; both groups were allotted the same study time. Roher et al. found that overlearning produced significantly higher retention after a one-week interval, but at a three-week retention test there was little difference between the high and low groups.

Rate of Reinforcement

There is a large body of literature examining the effects of rate of reinforcement on response strength in nonhumans. Unfortunately, this literature is primarily focused on how reinforcement rate as a variable influences the resistance of steady-state performance to disruption. Only a few studies relate to the characteristics of fluent performance.

In general, high rates of reinforcement increase resistance to extinction (Nevin, 1988; Leiving & Lattal, 2003). Extinction is fundamentally different from procedures that test retention in that during extinction, responses within a previously reinforced context are now not reinforced. This procedure leads to decreased, and eventually no, responding. This is contrasted with retention in that during the retention interval, the response is not available or discriminative stimuli that signal the response will be reinforced are not present. Ostensibly, by removing the extinction procedure and simply allowing a retention interval in which the response is not reinforced to pass, as with extinction, any disruptions of performance during the retention interval would have more effect on performance with a lower associated rate of reinforcement.

In a delayed-matching-to-sample paradigm (DMTS), subjects are required to emit a response to a stimulus, then a delay interval is imposed during which the stimulus is not present, after which the stimulus is presented again with a distracting stimulus, and a response to the correct stimulus produces reinforcement. Using pigeons in an operant setting, a pecking key may be lit green. The pigeon would peck the key, then after a delay interval, two other keys would be lit, one green and the other red, with the positions of key colors determined randomly. Pecking the green key would result in access to food. This delay period is similar to the retention interval in that no responses are signaled or occur during the interval. The paradigm is nearly the same: A stimulus is presented, a response occurs, then after a period of time the stimulus is presented again and a correct response to that stimulus is reinforced. The difference between this and a fluency study, of course, is that in a fluency study significant practice occurs on the initial response before the retention interval.

Nevin and Grosh (1990) trained pigeons under DMTS but signaled the size of reinforcers prior to each trial. Subjects were more accurate during trials in which correct responses yielded larger reinforcers (i.e. longer access to food). However, when performance was disrupted with sodium pentobarbital, reduced exposure to the sample, and the addition of new stimuli to the experimental chamber (a light was turned on) there was no difference in disruption between trials with different amounts of reinforcement. Nevin, Milo, Odum, and Shahan (2003) trained four pigeons on a DMTS task during which trials of one color were associated with a low probability of reinforcement (0.2) and trials of a second color were reinforced with a high probability (0.8). Performance was disrupted by prefeeding, response-independent food presentations, increasing the delay between the sample and the choice test, and extinction. Disruptors affected response rates and accuracy in the low probability component significantly more than responses rates and accuracy in the high probability component. These studies suggest that discriminated responding can be strengthened by increased rates of reinforcement.

The study of endurance of responses trained under high reinforcement rates has occupied the majority of the behavioral momentum experimental literature. Typically, responses associated with stimuli correlated with higher rates of reinforcement are less susceptible to disruption (Nevin, 1992). It is important to note that this effect has been seen irrespective of response rates, and at times lower response rates are seen in components where reinforcement rate is higher. It is also notable that this effect is seen within conditioned discriminations in humans. Dube and McIlvane (2002) trained developmentally delayed persons to make 2-choice simultaneous discriminations under continuous reinforcement (each correct response was reinforced) or one of two variable-ratio reinforcement schedules: variable-ratio 2 or variable-ratio 4 (reinforcement was provided after a variable number of correct responses with the mean being 2 or 4 correct trials). After responding was stable, the discriminations were reversed. Most subjects displayed more errors following reversal in the continuous reinforcement component, suggesting that this performance was more resistant to change due to higher rates of reinforcement.

Walker (2005) examined the effects of high and low rates of reinforcement on fluency training. Twelve college students were divided into two groups, both groups trained to fluency on math skills. The high rate group (HR) received feedback and response-contingent points exchangeable for money every minute. The low rate group (LR) received feedback and points every five minutes. Each group was then tested on endurance, application, problem solving, and retention tests. No significant differences were found on any of the measures.

A few studies have examined the effects of more frequent or larger amounts of reinforcement on acquisition of responses. Although this is not a purported benefit of rate-building procedures, acquisition with fewer trials would be a promising development within education. Broner, Avila, Acuna, and Gallado (1998) assessed rats' acquisition of lever press responding when presses were reinforced on one of several tandem schedules. The tandem schedules comprised a random-interval (the next component was made available after the first response during time cycles of 1.5, 3, 6, and 12 s, with the probability of 0.1) and then a fixed-time schedule (food reinforcement was delivered after a fixed time). Under this procedure, rats that were performing under higher rates of reinforcement produced higher response rates faster then those performing under lower rates of reinforcement.

Rate of Responding

Rate of responding is typically studied as a dependent variable in operant conditioning, so it is not surprising that studies where response rates are deliberately manipulated as an independent variable are rare. Within respondent research, however, a large body of literature exists which examines the effects of trial spacing on associative learning. The primary phenomenon studied within this literature is the “spacing effect” and the evidence here is surprisingly in direct disagreement with the idea that speedy performance yields better retention of learned skills.

The “spacing effect” or “distributed practice effect” is shown when subjects practice paired associates, cued recall, list recall or other types of stimulus-response or stimulus paired learning. When these tasks are trained with trials distributed across time in a more spaced manner retention is greater at longer retention intervals (Cepeda, Pashler, Vul, Wixted, & Roher, 2006). However, this research is fundamentally different form rate-building in that it compares only a few massed presentations to a similar number of spaced presentations. Additionally, presentations are considered massed if presented within a smaller window of time than spaced presentations, so that massed trials may occur within an hours time while spaced trials occur twice each day for a few days. Rate-building is not a concern in this literature; therefore, it has little relevance on the current study, but should be noted.

CHAPTER III

PURPOSE

The purpose of the current study was to examine the individual effects of number of trials, rate of responding, and rate of reinforcement on learning and performance. To ensure experimental control, these effects were studied using pigeons in a laboratory setting.

CHAPTER IV

GENERAL METHOD

Repeated Acquisition

The repeated acquisition procedure was first described by Boring (1963) as a procedure that allowed experimenters to study steady states of response acquisition (i.e., learning) across multiple sessions using a within-subject experimental design. The procedure arranges required sequences of responding on several operanda. The completion of the required sequence results in the presentation of some reinforcing stimulus. The position of required responses can be changed by the experimenter so that the subject must relearn a new sequence of responses. The procedure allows for the study of acquisition of response sequences as well as stability of sequences once acquired, and is of common use in assessing the behavior effects of substances such as abused drugs (Poling & Byrne, 2000).

For example, Poling, Cleary, Berens, and Thompson (1990) trained pigeons to produce a series of responses that completed a four-link behavioral chain. During each link in the chain all three response keys were illuminated with a color designated for that particular link (yellow, red, green, or white). One key during each link was designated as the correct key. A response on this key advanced the chain to the next link, and after the chain was completed, food was presented. Responses on incorrect keys resulted in an 8-s timeout. The position of correct keys was changed each session so that pigeons had to acquire a new sequence of responses each day. They then tested the effect of various neuroleptics on performance under this procedure.

The repeated acquisition procedure has been adapted to study retention of response sequences. For example, Thompson, Mastropaolo, Winsaur, and Moerschbacher (1985) required sequential responding on three keys; the correct key was determined by which of four geometric shapes was presented. Subjects (patas monkeys) were required to respond on the correct key during the presentation of each geometric shape in order to complete a behavior chain and receive food reinforcement. The correct key for each shape was changed daily in order to assess repeated acquisition. Additionally, after meeting a criterion of five complete chains without an error, subjects entered a delay period in which stimuli were not presented and responses produced no programmed consequences. After the delay period the subjects were again exposed to repeated acquisition trials which required the response sequence trained before the delay. Delay periods of 5, 30, 60 and 180 m were programmed, and retention measures declined as a function of the delay period.

Subjects

Six adult female White Carneau pigeons (*Columbia livia*) served as subjects for the studies. The subjects were obtained from Palmetto Pigeon Plant (Sumter, SC) and were retired breeder pigeons approximately five years of age. They were housed in home cages located in an animal colony with a 12 h light/12 h dark cycle grit and water were freely available in the home cages. When first obtained, the birds were allowed free access to food and weighed daily for seven consecutive days. An average weight was calculated from the last three days; this weight was used as the “free-feeding” weight. Eighty-percent of this weight was then calculated for each subject and their body-weights were reduced through restricted feedings to this level. The birds were maintained close to this weight (± 15 grams) by daily feedings after experimental sessions. The procedures described and treatment of subjects was reviewed and deemed acceptable by an Institutional Animal Care and Use Committee (IACUC).

Apparatus

Experimental sessions were conducted in MED Associates (St. Albans, VT) operant test chambers with dimensions 30 cm high 25 cm wide and 30 cm long. Each chamber was outfitted with three pecking keys located 21 cm from the floor. The keys were separated by 6 cm, were about 2 cm in diameter, and could be lit from the back with green, red, or white light. Located below the pecking keys was a 7 cm × 7 cm opening within which a food hopper could be raised to allow access to mixed grain. When the hopper was raised, the opening was illuminated. A 7-W bulb (houselight) illuminated the chamber interior during sessions. The chambers were located within sound attenuating boxes and a fan provided circulation and masking white noise during sessions. An IBM-compatible computer running MED-PC software under Microsoft Windows 98 was used to control experiments and collect data.

Training Procedures

Subjects were initially trained to peck response keys using an autoshaping procedure (Brown & Jenkins, 1968). During autoshaping, the pigeons were placed in the operant chamber illuminated by the houselight. On average (variable inter-trial interval 45 s) every 45 seconds, a key was lighted for 6 s, after which the food hopper was raised and access to grain was provided for 3 s. The location (left, center, right) and color (red, white, green) of key illuminations was determined at random with the exception that all colors and positions appeared equally often. Responses in this arrangement were recorded but produced no programmed consequences. Responses on the lit key were recorded as well as trials with at least one response. Sessions lasted until 45 key light-food pairings (trials) occurred.

After each subject was pecking reliably on all three colors (red, green, white) in all three positions (10 – 14 sessions) the inter-trial interval was set at 5 s and responses turned off the key light and immediately raised the food hopper for 3 s; the key light color and position was chosen randomly for each trial. During this procedure, sessions lasted for 50 trials or 60 min, whichever came first. Total responses and time to complete 50 trials were recorded for each session. When subjects reliably responded under this second procedure (<10 sessions), the procedure was changed to include a second lit key on each trial (the distracter key). The position of the distracter key was randomly determined from the two remaining positions and its color always matched the color of the other key lit during the trial. Responses to the distracter key had no programmed consequences. Sessions lasted for 50 trials or 60 min during this procedure. After subjects responded reliably (5-7 sessions), the procedure was again changed to include two distracter keys and one “correct” key on each trial. Again, the distracter keys were lit the same color as the correct key and pecking the distracter keys produced no programmed consequences. After subjects responded reliably to this schedule (7-10 sessions), food was presented only after three consecutive correct responses occurred. Subjects were exposed to this schedule until response rates stabilized over 10 sessions as determined by visual inspection of graphed response rates (about 20 sessions), after which the subjects were exposed to repeated acquisition sessions as described below.

General Final Procedure

Repeated acquisition of three-link chains was arranged in the manner outlined by Thompson (1978). During the first link of the chain all three pecking keys (left, center, right) were lit red and one key was determined as the “correct” key for this link of the chain. A response on the correct key immediately turned off the key lights and advanced the program to the next link during which the keys were lit a different color and the position of the “correct” key changed. Incorrect responses were followed by a 1-s timeout, after which the link was re-presented. The position of the correct key during each link of the chain stayed the same during the course of a session. The hopper was raised for 3.5 s after the third link was completed, after which the first link was again presented. Positions of correct keys were determined at random each session, save that no position was designated as correct for two consecutive links, and no position-color combination was repeated consecutively across sessions. Sixteen chains were trained in all (see Appendix A for a procedural outline).

Each session, correct and incorrect responses were recorded for each link in each chain. After accuracy (percent of total responses that were errors) stabilized (about 40 sessions), three chains were selected which had the least variance across sessions within and between subjects and used all three positions during the chain. These three chains were used during the following experiments. Presentation of chains was arranged so that no key light color was associated with the same position for two consecutive sessions. A table detailing arrangement of conditions during each session can be found in Appendix B. A table of correct key positions for each experiment can be found in Appendix C.

Dependent Variables

For each session, responses, correct responses, time in seconds, latency to respond, and reinforcers delivered were recorded for each chain (experiments III, IV, and V) or five-chain bin (experiments I, II, and VI) completed by each subject. These data were used to calculate percent correct, latency to respond, responses per second, reinforcers per second, first chain completed without an error, and rate of errors per chain after the first chain with no errors. Data were analyzed by two-factor analysis of variance with repeated measures across subjects. When experimental design was unbalanced (errors per chain after first correct chains, comparison of rate-controlled components of experiments four and five) a general linear model analysis of variance was employed, again with two factors and repeated measures across subjects. For all statistical comparisons in all situations, the alpha level was set at 0.05 for determining significance. Interaction plots are presented for significant interactions (chain × condition) when overall ANOVAs were also significant.

CHAPTER V

EXPERIMENT I

Purpose

The purpose of the first experiment was to determine the effects of trial spacing during repeated acquisition on retention, endurance, and acquisition of behavioral chains. The study was designed to be comparable to human studies comparing rate-building procedures to procedures that forced slow responding (e.g., Makepeace, 1998). Number of responses was held constant across slow (rate-controlled) and fast (rate-building) conditions, and rate of responding and rate of reinforcement were allowed to vary. The study was intended to examine whether the number of trial presentations (degree of overlearning) contributes to the benefits of rate-building procedures.

Method

Four subjects (XF, 11407, XD, 13485) participated in this study. Daily sessions comprised two components. During the first component three five-chain bins were arranged wherein the position of correct keys at each link in the chain was identical to the positions trained during the second component of the session the day before. This allowed for a 23-h retention test. During the second component, new correct response positions were set for each link of the chain. After the first component ended, a 30-s blackout occurred during which the houselight and key lights were extinguished and responses had no programmed consequences. During each of the components, the hopper was raised for 3.5 s under a fixed-ratio (FR) 5 schedule, where five chains had to be completed before food was delivered. Two different conditions were arranged during the second component; each condition was presented for three consecutive sessions so that each of the three chains used during the experiment was presented for each condition. During the first condition, the rate-building condition, sessions ended after a fluency criterion was reached during the training component. For this criterion to be reached each subject had to complete four five-chain bins in a row, each in 45 s. This rate criterion was determined by examining fast, accurate performance during previous sessions.

For the second condition, the rate-controlled condition, each of the three chains was repeated again in the same order. Training in the second component was now arranged so that trials were presented in a spaced fashion. A delay of 5 s was inserted following a correct response on the first and second links in the chain. A correct response still immediately turned off the key lights, but the next link in the chain was delayed. Incorrect responses, as in previous conditions, extinguished the key lights and the house light, and led to a 1-s timeout before the link was presented again. Delivery of reinforcement following a correct response in the third link was not delayed during the second condition. Sessions ended during the second condition when, for each subject, the same number of responses were emitted as in the rate-building condition during the corresponding chain. Each condition was presented twice, so that the experiment consisted of 12 consecutive sessions.

Results

Mean percent correct, mean reinforcers per second, mean responses per second, and responses for the training component by condition are shown in Figure 1. Mean percent correct, and errors per bin for the retention test component by condition are presented in Figure 2. Mean percent correct in the first and last five completed chains in the training component and the first five chains in the retention component are presented by condition in Figure 3. Analysis of variance results for each measure during training and retention components are listed in Tables 1 and 2, respectively. During the training component, mean accuracy was significantly higher during the rate-building condition.

Of the three variables of interest (rate of reinforcement, rate of responding, and responses), both rate of reinforcement and rate of responding were significantly higher during the rate-building condition. Number of responses was not significantly different across conditions, as arranged by the procedure. Mean percent correct during the retention test component was significantly different across conditions. Twenty-three-hour retention was demonstrated by the significantly higher mean percent correct during the first five chains of the retention tests when compared to the first five chains during the training component. The effect of the retention interval is demonstrated by the significantly lower mean percent correct during the first five chains of the retention component when compared to the last five chains of the training component. There was little difference between condition means for errors during the first bin of retention tests. This difference was higher during the second bin, and finally significantly different during the third bin.

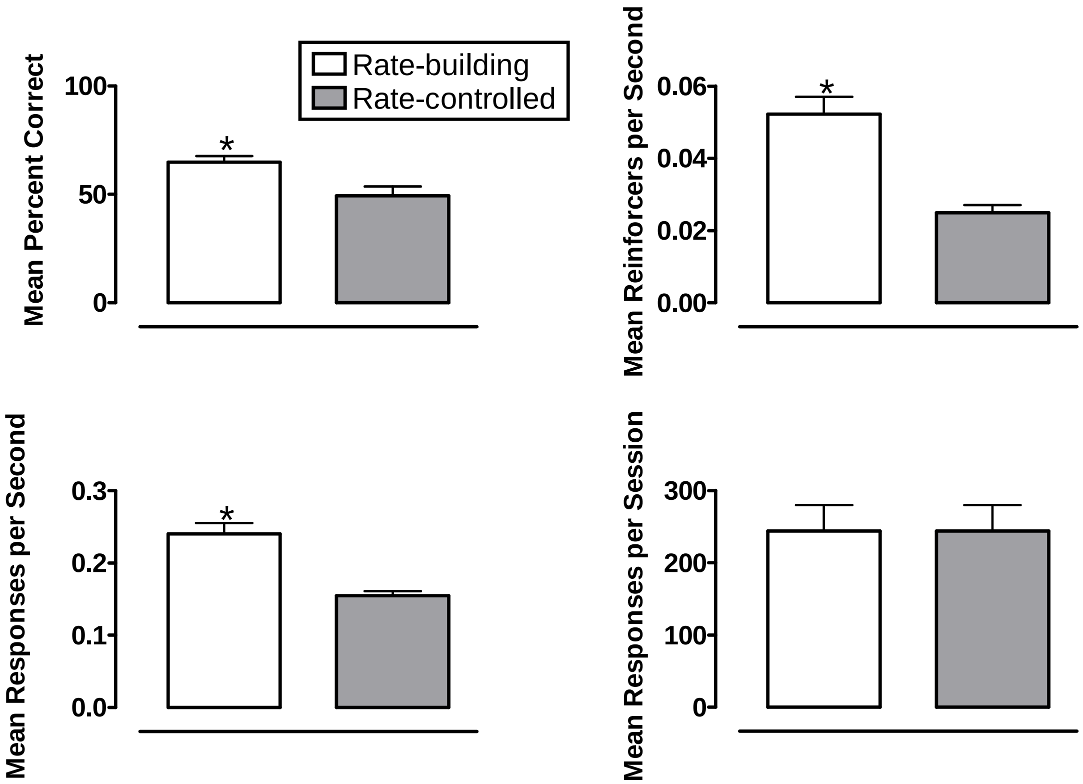


Figure 1. Mean Percent Correct, Reinforcement Rate, Response Rate, and Responses for the Training Component during Each Condition during Experiment I with 95% Confidence Intervals. Significant Differences are marked with Asterisks.

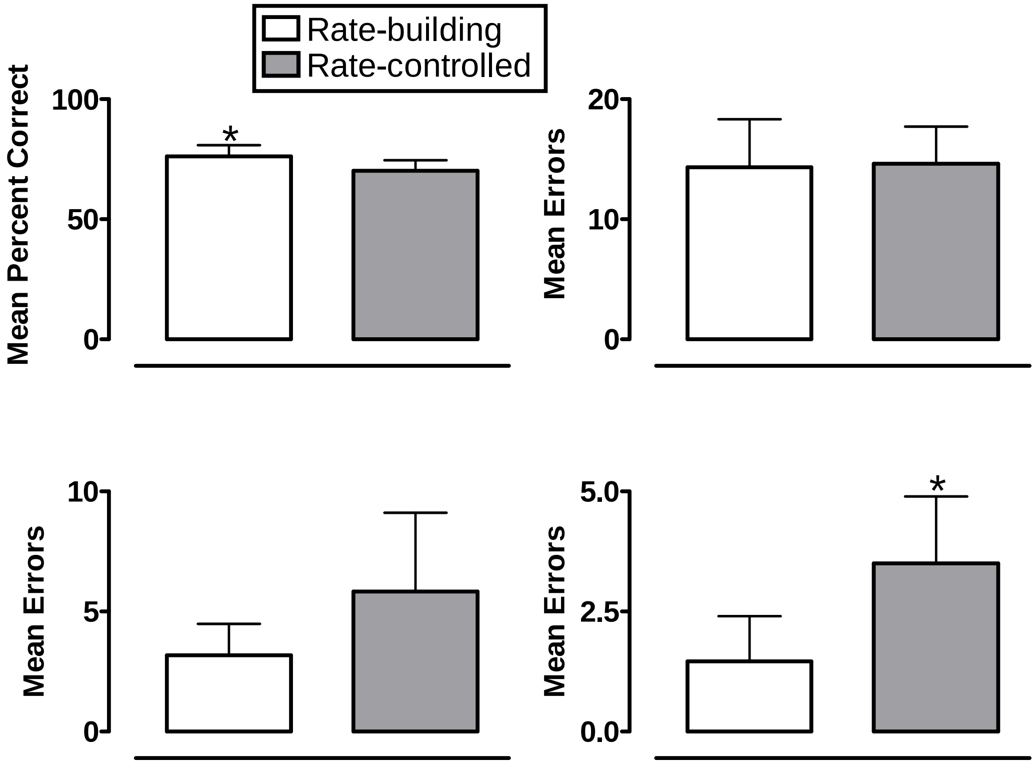


Figure 2. Mean Percent Correct, and Errors per Bin for the Retention Component during Each Condition of Experiment I with 95% Confidence Intervals. Significant Differences are marked with Asterisks.

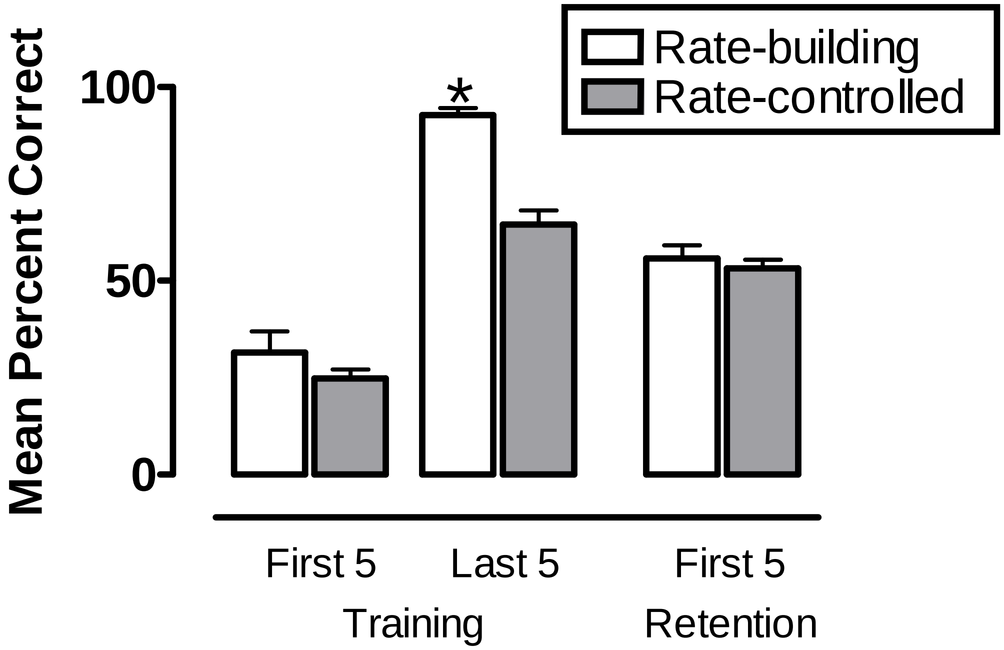


Figure 3. Mean Percent Correct, during First and Last Five Chains during Training and First Five Chains during Retention across Conditions of Experiment I with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

Table 1

Analysis of Variance Results for Training Component Experiment I

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	2867.52	2867.52	39.48	0.008
Chain	2	106.17	53.08	0.79	0.496
Subject	3	289.4	96.47		
Condition × Chain	2	383.17	191.58	2.69	0.084
Subject × Condition	3	217.9	72.63		
Subject × Chain	6	403.67	67.28		
Error	30	2139.17	71.31		
Responses					
Condition	1	0	0	**	
Chain	2	90878	45439	4.48	0.064
Subject	3	86529	28843		
Condition × Chain	2	0	0	0	1
Subject × Condition	3	0	0		
Subject × Chain	6	60848	10141		
Error	30	98800	3293		
Response rate					
Condition	1	0.0887292	0.0887292	667.17	<0.001
Chain	2	0.0012309	0.0006154	0.74	0.516
Subject	3	0.0053219	0.001774		
Condition × Chain	2	0.0006131	0.0003066	0.45	0.64
Subject × Condition	3	0.000399	0.000133		
Subject × Chain	6	0.0049878	0.0008313		
Error	30	0.0203193	0.0006773		
Reinforcement rate					
Condition	1	0.00891288	0.00891288	188.02	0.001
Chain	2	0.00001755	0.00000878	0.13	0.882
Subject	3	0.00007172	0.00002391		
Condition × Chain	2	0.00023656	0.00011828	1.43	0.254
Subject × Condition	3	0.00014221	0.0000474		
Subject × Chain	6	0.00041134	0.00006856		
Error	30	0.00247349	0.00008245		

Table 1—Continued

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct for first five chains					
Condition	1	533.99	533.99	3.19	0.172
Chain	2	194.67	97.34	2.43	0.169
Subject	3	832.78	277.59		
Condition × Chain	2	231.17	115.58	1.35	0.273
Subject × Condition	3	502.52	167.51		
Subject × Chain	6	240.69	40.12		
Error	30	2560.33	85.34		
Mean percent correct for last five chains					
Condition	1	9625.5	9625.5	20.7	0.02
Chain	2	441.1	220.5	1.13	0.382
Subject	3	830	276.7		
Condition × Chain	2	731	365.5	2.35	0.112
Subject × Condition	3	1395.2	465.1		
Subject × Chain	6	1166.8	194.5		
Error	30	4657.8	155.3		

Table 2

Analysis of Variance Results for Retention Component Experiment I

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	432	432	27.48	0.014
Chain	2	168.2	84.1	0.95	0.438
Subject	3	943.4	314.5		
Condition × Chain	2	78	39	0.34	0.714
Subject × Condition	3	47.2	15.7		
Subject × Chain	6	531.3	88.6		
Error	30	3427.8	114.3		
First five chains					
Condition	1	1.02	1.02	0.11	0.758
Chain	2	135.17	67.58	1.14	0.381
Subject	3	570.9	190.3		
Condition × Chain	2	32.17	16.08	0.22	0.801
Subject × Condition	3	26.9	8.97		
Subject × Chain	6	356.67	59.44		
Error	30	2153.17	71.77		
Second five chains					
Condition	1	85.33	85.33	6.27	0.087
Chain	2	13.63	6.81	0.24	0.797
Subject	3	78.17	26.06		
Condition × Chain	2	43.79	21.9	0.52	0.601
Subject × Condition	3	40.83	13.61		
Subject × Chain	6	173.71	28.95		
Error	30	1268.54	42.28		
Third five chains					
Condition	1	50.021	50.021	86.78	0.003
Chain	2	19.542	9.771	2.22	0.19
Subject	3	15.729	5.243		
Condition × Chain	2	19.792	9.896	1.05	0.362
Subject × Condition	3	1.729	0.576		
Subject × Chain	6	26.458	4.41		
Error	30	282.708	9.424		

Discussion

The rate-building condition clearly led to enhanced performance when compared to the rate-controlled condition. This is demonstrated by the difference in mean percent correct between the two conditions in training components. The statistically significant difference in mean percent correct during retention tests demonstrated an advantage for the rate-building condition. The increasing difference in errors by bin during retention tests suggests that after a 23-h retention interval, training during the rate-building condition resulted in faster reacquisition of learned chains. Taken together, the results from this experiment suggest that rate-building procedures do enhance performance, and that this enhancement is not due to an increased number of trials or overlearning. However, because rate of reinforcement and rate of responding were both significantly higher during the rate-building condition, this study does not provide evidence that rate of responding alone affects performance.

CHAPTER IV

EXPERIMENT II

Purpose

Experiment 1 demonstrated enhanced performance when number of responses was held constant and rate of responding and rate of reinforcement varied. Experiment 2 examined the effects of varying rate of reinforcement with rate of responding and number of responses held constant.

Method

The same four subjects (XF, 11407, XD, 13485) participated in this study. Procedures were identical to those of the rate-building condition in Experiment 1, except that two different conditions were arranged in Experiment 2. During the first condition, the HR (high reinforcement) condition, food was provided under an FR 3 schedule, where three completed chains were required to raise the food hopper. During the second condition, the LR (low reinforcement) condition, an FR 6 schedule was imposed, where six completed chains were required to raise the food hopper. All sessions ended as in condition one of Experiment 1, once four bins of five chains were completed under 45 s. As in Experiment 1, this experiment consisted of twelve consecutive sessions with each condition repeated twice for three consecutive sessions.

Results

Despite a significant difference in reinforcement rate between the training components of the two conditions, no significant differences were seen in mean percent correct measures in training or retention conditions. Mean percent correct, responses per second, reinforcers per second, and responses per session by condition for the training component are presented in Figure 4. Mean percent correct by condition for the retention test component is presented in Figure 5. Mean percent correct for the first and last five completed chains during the training component and the first five chains during the retention component by condition are presented in Figure 6. Analysis of variance results for the training and retention components are listed in Tables 3 and 4, respectively.

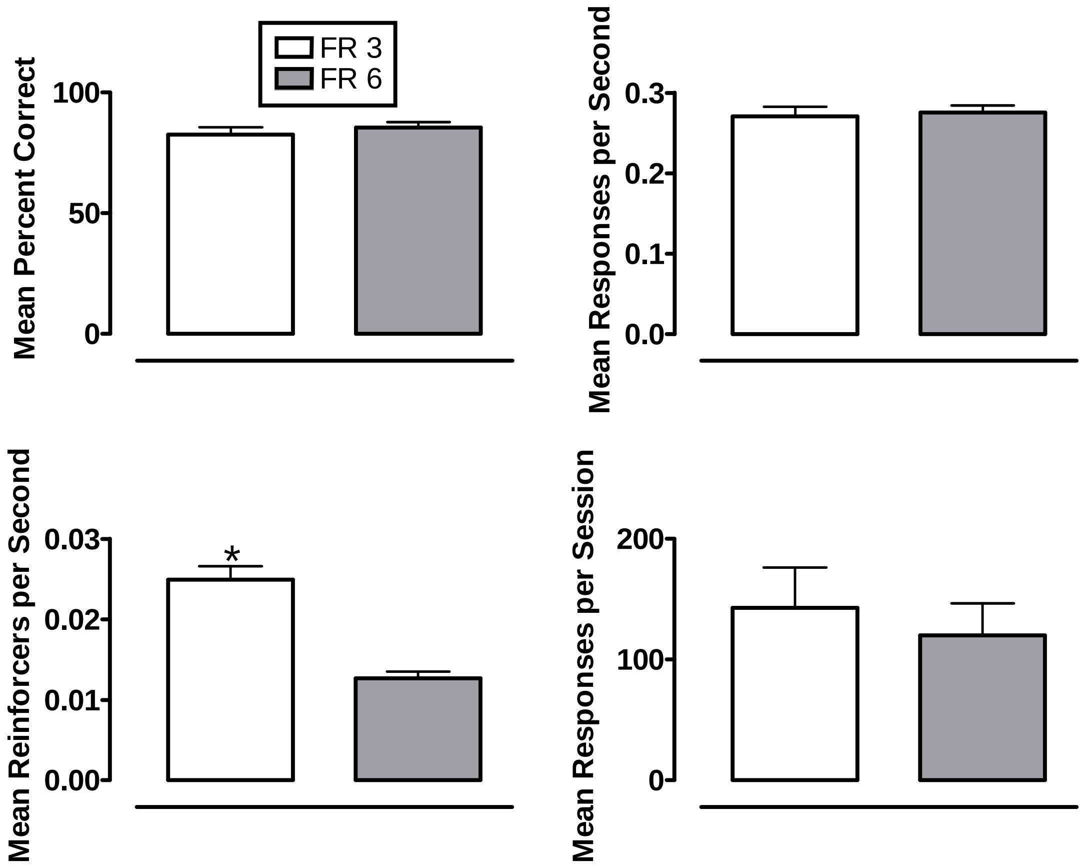


Figure 4. Mean Percent Correct, Response Rate, Reinforcement Rate and Responses for the Training Component during Each Condition of Experiment II with 95% Confidence Intervals. Significant Differences are marked with Asterisks.

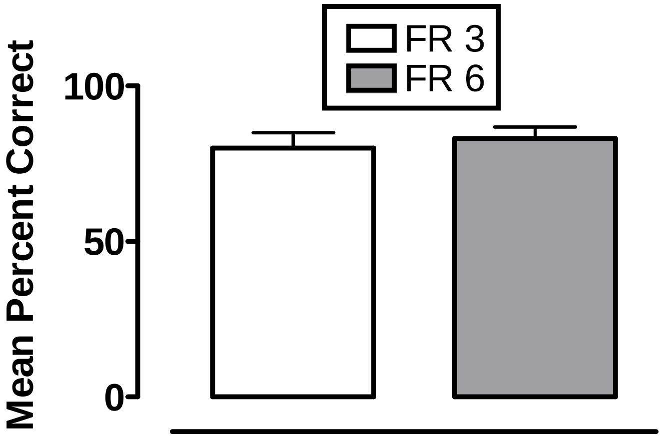


Figure 5. Mean Percent Correct for the Retention Component during Each Condition of Experiment II with 95% Confidence Intervals.

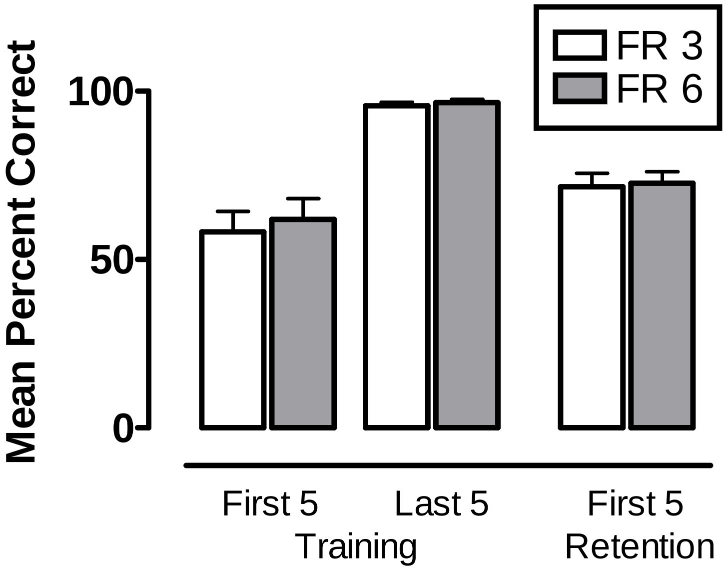


Figure 6. Mean Percent Correct during First and Last Five Chains during Training and First Five Chains during Retention across Conditions of Experiment II with 95% Confidence Intervals.

Table 3

Analysis of Variance Results for Training Component Experiment II

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	111.02	111.02	4.09	0.136
Chain	2	243.04	121.52	4.19	0.073
Subject	3	196.56	65.52		
Condition × Chain	2	35.04	17.52	0.45	0.645
Subject × Condition	3	81.4	27.13		
Subject × Chain	6	174.13	29.02		
Error	30	1179.29	39.31		
Response rate					
Condition	1	0.0002872	0.0002872	0.49	0.533
Chain	2	0.0013408	0.0006704	1.75	0.252
Subject	3	0.0069715	0.0023238		
Condition × Chain	2	0.0006708	0.0003354	0.64	0.533
Subject × Condition	3	0.0017481	0.0005827		
Subject × Chain	6	0.0022992	0.0003832		
Error	30	0.0156566	0.0005219		
Reinforcement rate					
Condition	1	0.00180045	0.00180045	414.63	<0.001
Chain	2	0.00005136	0.00002568	5.23	0.048
Subject	3	0.0000039	0.0000013		
Condition × Chain	2	0.00002438	0.00001219	1.12	0.34
Subject × Condition	3	0.00001303	0.00000434		
Subject × Chain	6	0.00002945	0.00000491		
Error	30	0.00032706	0.0000109		
Trials					
Condition	1	6120	6120	4.01	0.139
Chain	2	1489	745	0.06	0.946
Subject	3	37677	12559		
Condition × Chain	2	1917	959	0.26	0.775
Subject × Condition	3	4574	1525		
Subject × Chain	6	79953	13326		
Error	30	111772	3726		

Table 3—Continued

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct for first five chains					
Condition	1	162.7	162.7	2.84	0.19
Chain	2	878.4	439.2	3.79	0.086
Subject	3	816.7	272.2		
Condition × Chain	2	33.9	16.9	0.07	0.932
Subject × Condition	3	171.7	57.2		
Subject × Chain	6	694.5	115.7		
Error	30	7241.5	241.4		
Mean percent correct for last five chains					
Condition	1	8.86	8.86	0.48	0.54
Chain	2	34.53	17.26	0.47	0.646
Subject	3	25.31	8.44		
Condition × Chain	2	94.53	47.27	1.89	0.168
Subject × Condition	3	55.89	18.63		
Subject × Chain	6	220.09	36.68		
Error	30	748.8	24.96		

Table 4

Analysis of Variance Results for Retention Component Experiment II

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	114.08	114.08	2.44	0.216
Chain	2	680.54	340.27	1.28	0.346
Subject	3	495.5	165.17		
Condition × Chain	2	47.54	23.77	0.37	0.694
Subject × Condition	3	140.42	46.81		
Subject × Chain	6	1601.13	266.85		
Error	30	1928.46	64.28		
Mean percent correct for first five chains					
Condition	1	12.9	12.9	0.14	0.729
Chain	2	2295.9	1148	0.93	0.446
Subject	3	473	157.7		
Condition × Chain	2	119.2	59.6	0.35	0.706
Subject × Condition	3	267.9	89.3		
Subject × Chain	6	7431.2	1238.5		
Error	30	5069.4	169		

Discussion

In Experiment 2, a significant difference in reinforcement rate across conditions produced no differences in training or retention mean percent correct. Training mean percent correct for both conditions was much higher than in the previous experiment and significantly fewer responses were required to meet the fluency criterion (about half as many). This suggests that subjects learned to discriminate each of the three chains, and could respond correctly without complete relearning each day. If this is the case, the results from the present experiment may reflect a ceiling effect and any effects of higher reinforcement rates may be less detectable.

The lack of effect suggests that if a) reinforcement rate affects learning and fluent performance the effect is slight and b) significantly greater differences in reinforcement rates than those analyzed in the present study are required for the effect to appear. Experiment 3 was designed to remove the possibility of a ceiling effect in order to provide a more sensitive procedure to study the effect of reinforcement rates on learning.

CHAPTER VII

EXPERIMENT III

Purpose

Due to the possibility of a ceiling effect in Experiment 2, the effect of rate of reinforcement was examined in Experiment 3 using a procedure that avoided the possible confound.

Method

All six subjects (XF, 1140, XD, 13485, 13576, 1224) participated in this study. As performance was consistently highly accurate during the previous experiment, additional chains plus those used in Experiment 2 were arranged in this study. The three additional chains were arranged so that first-link positions were identical to those of the first set of three, but the remaining two positions were dissimilar. If birds were discriminating the chain based on the correct position during the first link, the additional three chains would disrupt this discrimination. In Experiment 3, a third component was arranged between the retention test component and the training component. During this new component, the distracter component, 20 five-chain bins had to be completed before moving on to the training component. The three additional chains were trained during the distracter component.

It is also possible that during the previous experiment the relatively high accuracies represented a ceiling effect due to the number of trials allowed to occur before the criterion was reached. If performance was relatively poor, subjects could continue to respond, possibly increasing overall accuracies by performing just below criterion for an extended period. To control for this possibility, a limit of 120 responses was arranged in Experiment 3. This response limit was the approximate mean value required to reach criterion during the previous experiment.

Reinforcement rate during the current experiment was manipulated by providing reinforcement during the training component under a variable-interval (VI) schedule, where on average every 60 s during the LR condition and every 40 s during the HR condition the hopper was raised after a chain was completed (VIs were arithmetic). A VI 50-s schedule was arranged during the first two components (retention and distracter). Each time the hopper was raised, a probability function determined whether food remained available for 3.5 s ($p = 0.25$) or the hopper was deactivated immediately ($p = 0.75$). Deactivating the hopper immediately resulted in some stimuli associated with primary reinforcement (light flash, click of hopper), but did not allow subjects to consume any food; this arrangement was considered conditioned reinforcement, whereas 3.5-s access was considered primary reinforcement. This procedure is typically used within repeated acquisition assays to thin schedules of primary reinforcement (Poling, Cleary, Berens, & Thompson, 1990). As in the previous experiments, 12 consecutive sessions were conducted with conditions alternating every three sessions. Errors were now collected for each chain, rather than in bins of five chains. This allowed for a more fine-grained analysis of acquisition and endurance (stability) of performance.

Results

Although reinforcement rate was significantly higher in the HR condition, mean percent correct during training and retention components was equivalent across conditions. Response rate was higher during the LR component, while mean latency to respond was significantly lower. Acquisition as measured by the first chain completed without an error was not significantly different across conditions; neither was endurance as measured by errors per chain after acquisition. Figure 7 displays means for percent correct, responses per second, reinforcers per second, latency per response, acquisition, and endurance measures for the training component across conditions. Figure 8 presents mean percent correct, latency per response, and acquisition and endurance measures across conditions for the retention component. Figure 9 shows mean percent correct for the first and last five completed chains during the training component and first five completed chains during the retention component by condition. Tables 5 and 6 list the results of analysis of variance for each dependent variable during the training and retention components, respectively.

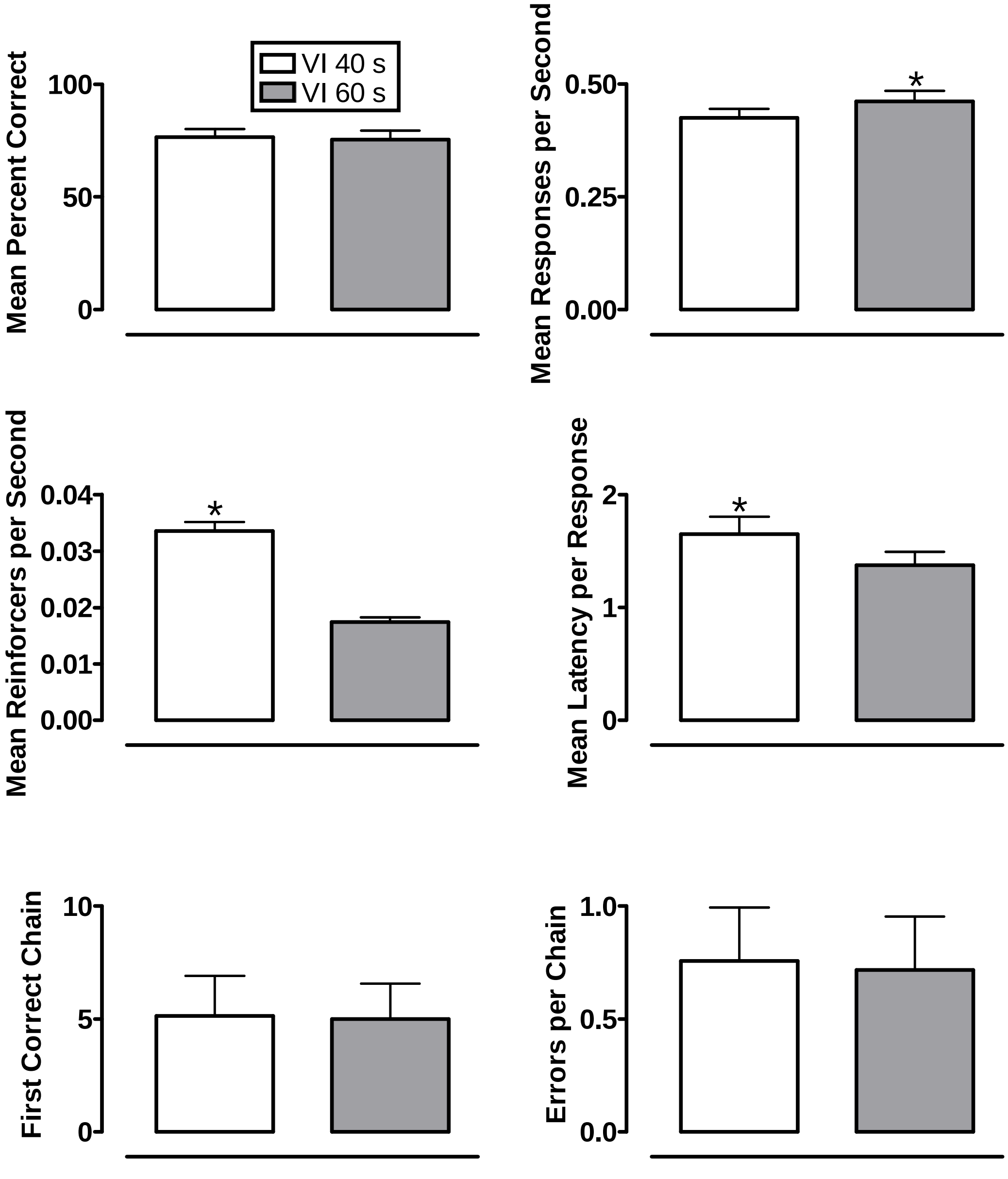


Figure 7. Mean Percent Correct, Response Rate, Reinforcement Rate, Latency per Response, First Chain without Error, and Errors per Chain after First Chain without Error for the Training Component during Each Condition of Experiment III with 95% Confidence Intervals. Significant Differences are marked with Asterisks.

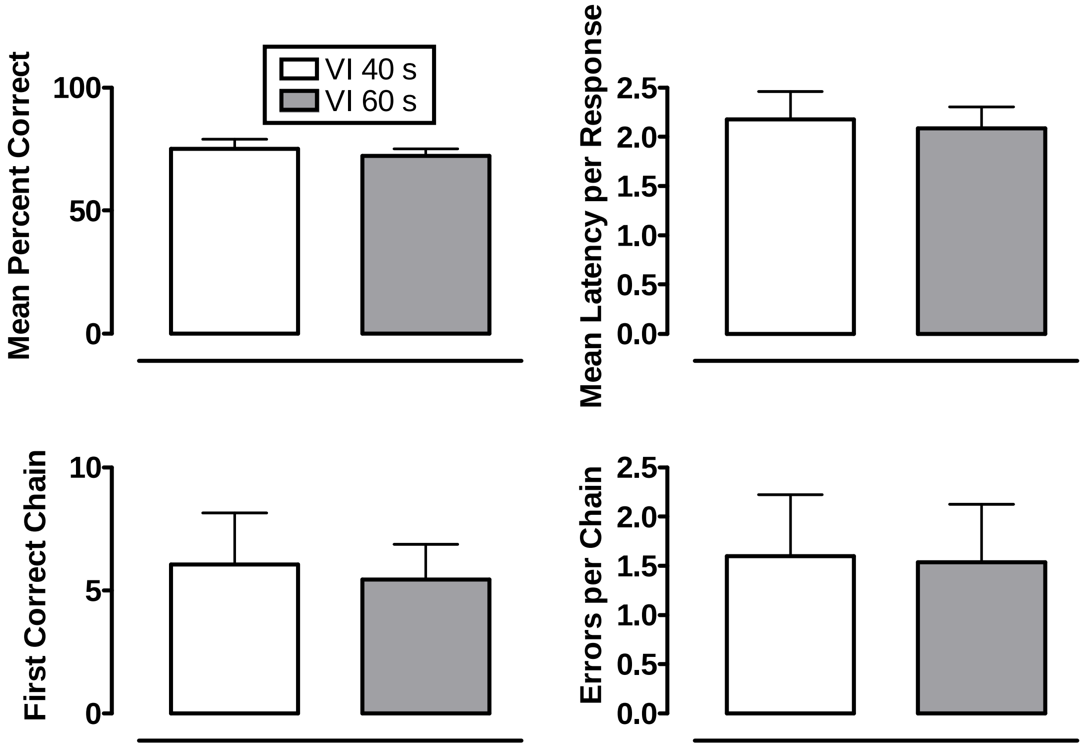


Figure 8. Mean Percent Correct, Latency per Response, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Retention Component across Conditions during Experiment III with 95% Confidence Intervals.

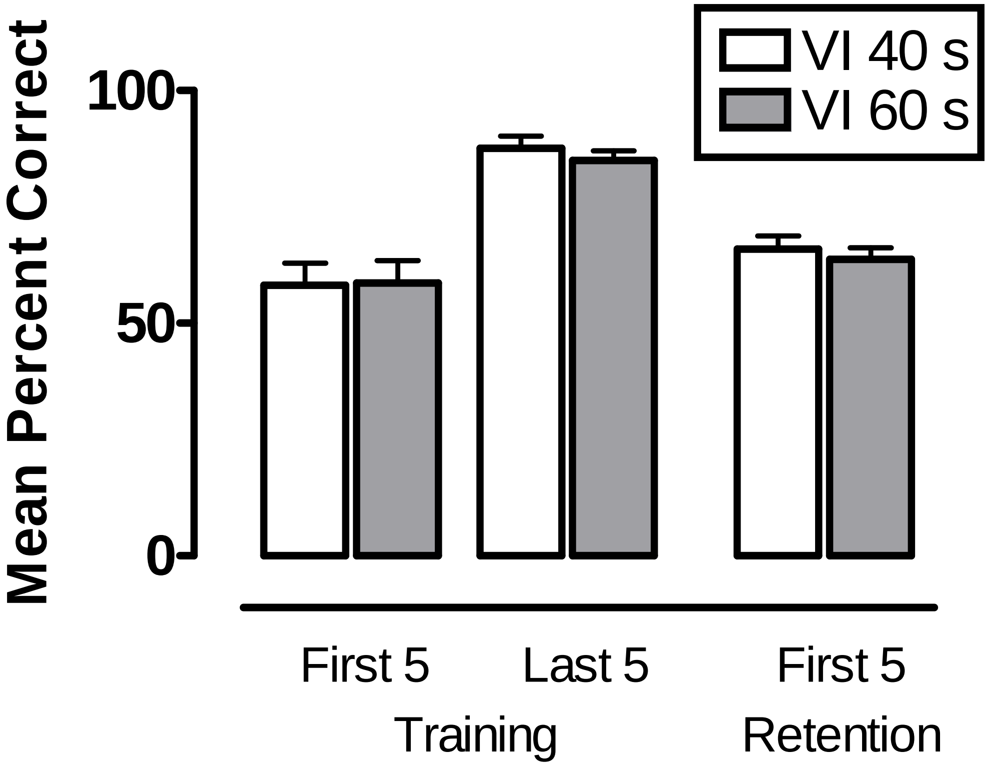


Figure 9. Mean Percent Correct during First and Last Five Chains during Training and First Five Chains during Retention across Conditions of Experiment III with 95% Confidence Intervals

Table 5

Analysis of Variance Results for Training Component Experiment III

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	0.89	0.89	0.01	0.917
Chain	2	1238.86	619.43	3.98	0.053
Subject	5	3047.44	609.49		
Condition × Chain	2	13.36	6.68	0.14	0.872
Subject × Condition	5	371.94	74.39		
Subject × Chain	10	1556.14	155.61		
Error	46	2237.31	48.64		
Response rate					
Condition	1	0.025016	0.025016	9.61	0.027
Chain	2	0.051363	0.025682	7.57	0.01
Subject	5	0.103524	0.020705		
Condition × Chain	2	0.000561	0.000281	0.08	0.919
Subject × Condition	5	0.013018	0.002604		
Subject × Chain	10	0.03394	0.003394		
Error	46	0.153411	0.003335		
Reinforcement rate					
Condition	1	0.00462637	0.00462637	363.88	<0.001
Chain	2	0.0000656	0.0000328	1.86	0.206
Subject	5	0.0000172	0.00000344		
Condition × Chain	2	0.00002583	0.00001291	1.24	0.3
Subject × Condition	5	0.00006357	0.00001271		
Subject × Chain	10	0.00017679	0.00001768		
Error	46	0.0004809	0.00001045		
Latency per trial					
Condition	1	1.50222	1.50222	15.4	0.011
Chain	2	0.67295	0.33648	3.16	0.086
Subject	5	4.28951	0.8579		
Condition × Chain	2	0.0049	0.00245	0.03	0.969
Subject × Condition	5	0.48787	0.09757		
Subject × Chain	10	1.0642	0.10642		
Error	46	3.53973	0.07695		

Table 5—Continued

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct for first five chains					
Condition	1	59.76	59.76	0.63	0.464
Chain	2	867.65	433.83	1.14	0.358
Subject	5	3654.65	730.93		
Condition × Chain	2	352.97	176.48	2.09	0.135
Subject × Condition	5	475.89	95.18		
Subject × Chain	10	3807.34	380.73		
Error	46	3880.87	84.37		
Mean percent correct for last five chains					
Condition	1	95	95	0.62	0.466
Chain	2	873.9	436.9	1.23	0.332
Subject	5	2949.7	589.9		
Condition × Chain	2	318.3	159.1	1.48	0.238
Subject × Condition	5	763.9	152.8		
Subject × Chain	10	3539.2	353.9		
Error	46	4947.3	107.6		
First correct chain					
Condition	1	0.19	0.19	0.05	0.842
Chain	2	19.63	9.81	0.26	0.78
Subject	3	69.23	23.08		
Condition × Chain	2	7.63	3.81	0.32	0.727
Subject × Condition	3	11.9	3.97		
Subject × Chain	6	226.71	37.78		
Error	30	355.54	11.85		

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	0.035	0.147	0.147	0.15	0.721
Chain	2	1.669	1.161	0.58	0.37	0.701
Subject	3	1.432	0.449	0.15		
Condition × Chain	2	8.804	8.93	4.465	2.92	0.079
Subject × Condition	3	2.162	2.855	0.952		
Subject × Chain	6	9.333	9.333	1.556		
Error	18	27.483	27.483	1.527		

Table 6

Analysis of Variance Results for Retention Component Experiment III

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	102.72	102.72	1.06	0.351
Chain	2	77.19	38.6	0.31	0.74
Subject	5	1841.78	368.36		
Condition × Chain	2	63.53	31.76	0.61	0.546
Subject × Condition	5	485.61	97.12		
Subject × Chain	10	1245.64	124.56		
Error	46	2380.64	51.75		
Latency per response					
Condition	1	0.0993	0.0993	0.4	0.555
Chain	2	0.5477	0.2739	1.05	0.385
Subject	5	16.045	3.209		
Condition × Chain	2	2.2935	1.1467	5.04	0.011
Subject × Condition	5	1.2446	0.2489		
Subject × Chain	10	2.6008	0.2601		
Error	46	10.4698	0.2276		
Mean percent correct in first five chains					
Condition	1	38.2	38.2	0.13	0.729
Chain	2	93.4	46.7	0.21	0.812
Subject	5	3419	683.8		
Condition × Chain	2	68.2	34.1	0.22	0.806
Subject × Condition	5	1425.8	285.2		
Subject × Chain	10	2195.4	219.5		
Error	46	7221.4	157		
First correct chain					
Condition	1	6.75	6.75	0.18	0.703
Chain	2	33.167	16.583	1.06	0.404
Subject	3	25.833	8.611		
Condition × Chain	2	118.5	59.25	12.74	<0.001
Subject × Condition	3	114.75	38.25		
Subject × Chain	6	94.167	15.694		
Error	30	139.5	4.65		

Table 6—Continued

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
			Errors per chain after first correct chain			
Condition	1	0.0186	0.0064	0.0064	0.17	0.706
Chain	2	1.1547	0.9577	0.4789	2.41	0.17
Subject	3	4.9382	5.0576	1.6859		
Condition × Chain	2	0.5145	0.5691	0.2846	1.39	0.265
Subject × Condition	3	0.0888	0.11	0.0367		
Subject × Chain	6	1.1913	1.1913	0.1986		
Error	18	5.933	5.933	0.2046		

Discussion

Again, significantly higher reinforcement rates failed to have any detectable effect on training or retention mean percent correct. The addition of the distracter component effectively decreased accuracies during training and retention components, seemingly removing any ceiling effects. It is important to note that response rates were higher during the LR component, although not significantly. As response rate is one of the variables hypothesized to be responsible for improved learning, it should be noted that differences in performance due to reinforcement rate may have been offset somewhat by differences in response rate. It is likely, however, that the difference in response rate was due to increased post-reinforcement pausing under the HR procedure, where 3.5-s food deliveries occurred more frequently. Additionally, considering that the difference in reinforcement rate was highly significant, and difference in response rate was not highly significant, to offset effects of reinforcement rate any effects of response rate would have to be very strong.

CHAPTER VIII

EXPERIMENT IV

Purpose

Clear evidence in favor of a rate-building procedure was shown in Experiment 1. Two variables may have been responsible for this advantage: rate of reinforcement, or rate of responding. In the previous two experiments, high rates of reinforcement produced no detectable effect when compared to lower rates. The present experiment was designed to control rates of reinforcement and number of responses while manipulating rate of responding to determine the latter's effects on learning.

Method

Four subjects (XF, 11407, XD, 13485) participated in this study. As in Experiment 3, sessions comprised three components: retention test, distracter, and training. The same six chains were trained in their respective components. Reinforcement was made available in each component under a VI 50-s schedule with primary reinforcement occurring on a probability schedule ($p = 0.25$). During the training component in the rate-controlled condition, links were spaced as in Experiment 1, where a 5-s delay was programmed after each correct response. Additionally, a 5-s inter-trial interval was programmed during the training component of the rate-controlled condition. Sessions ended as in Experiments 1 and 2, where four five-chain bins had to be completed under 45 s during the training component of the rate-building condition. Sessions ended during the rate-controlled condition after a number of responses equivalent to responses in the corresponding chain of the rate-building condition. Each bird was exposed to each condition of interest twice, each time for three consecutive sessions.

Results

Mean percent correct during training was significantly different across conditions; however, the interaction between the conditions and individual chains was also significant. Mean response rate was significantly higher during the rate-building condition, while mean latency was significantly lower. Mean retention percent correct was significantly higher during sessions following the rate-building condition, mean latency per response was not significantly different across conditions during the retention component. The first chain without an error and subsequent error rates were also significantly different across conditions in both training and retention components. Figures 10 and 11 display all dependent variables across conditions for the training and retention components, respectively. Figure 12 presents mean percent correct for the first and last five completed chains during the training component and the first five chains completed during the retention component by condition. Tables 7 and 8 list all analysis of variance results for the training and retention components, respectively. Significant interactions are plotted in figures 13 and 14 for mean percent correct during training and first correct chain during training, respectively.

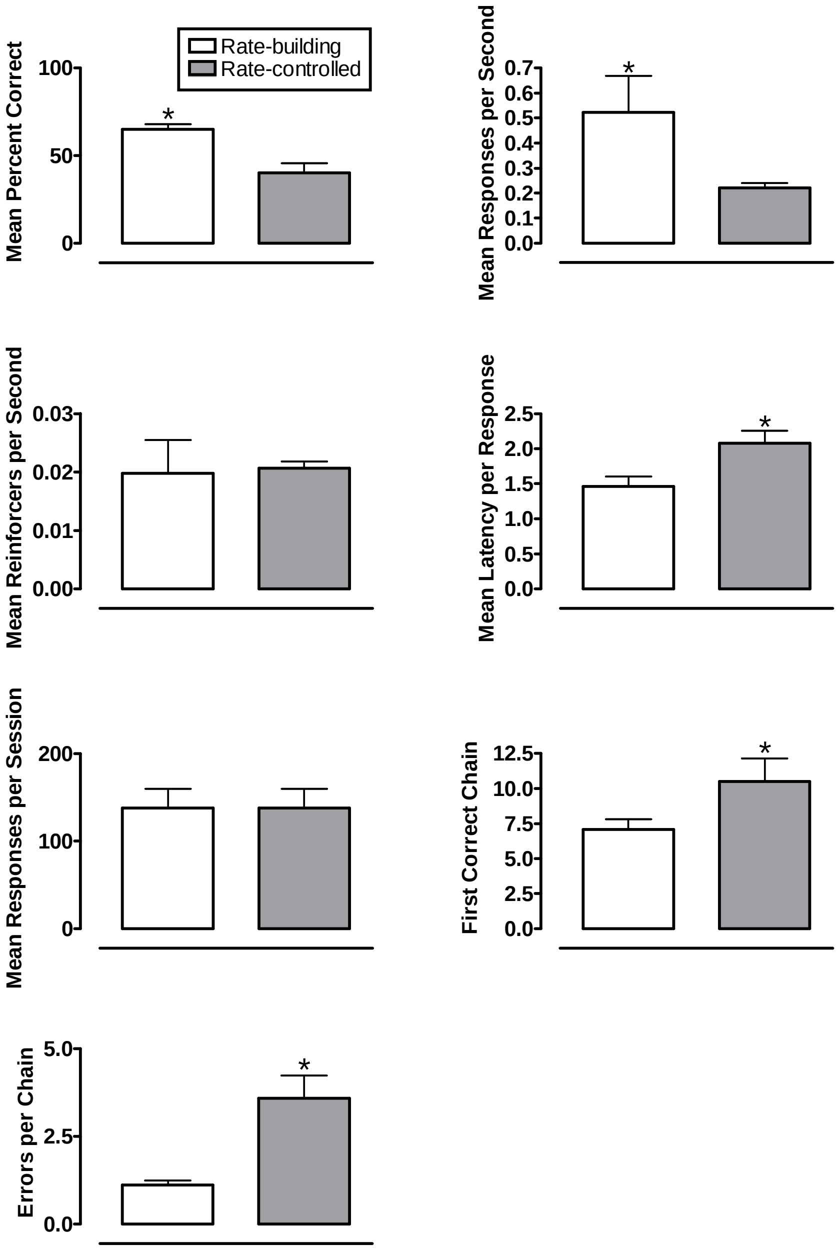


Figure 10. Mean Percent Correct, Response Rate, Reinforcement Rate, Latency per Response, Responses, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Training Component during Each Condition of Experiment IV with 95% Confidence Intervals. Significant Differences are marked with Asterisks

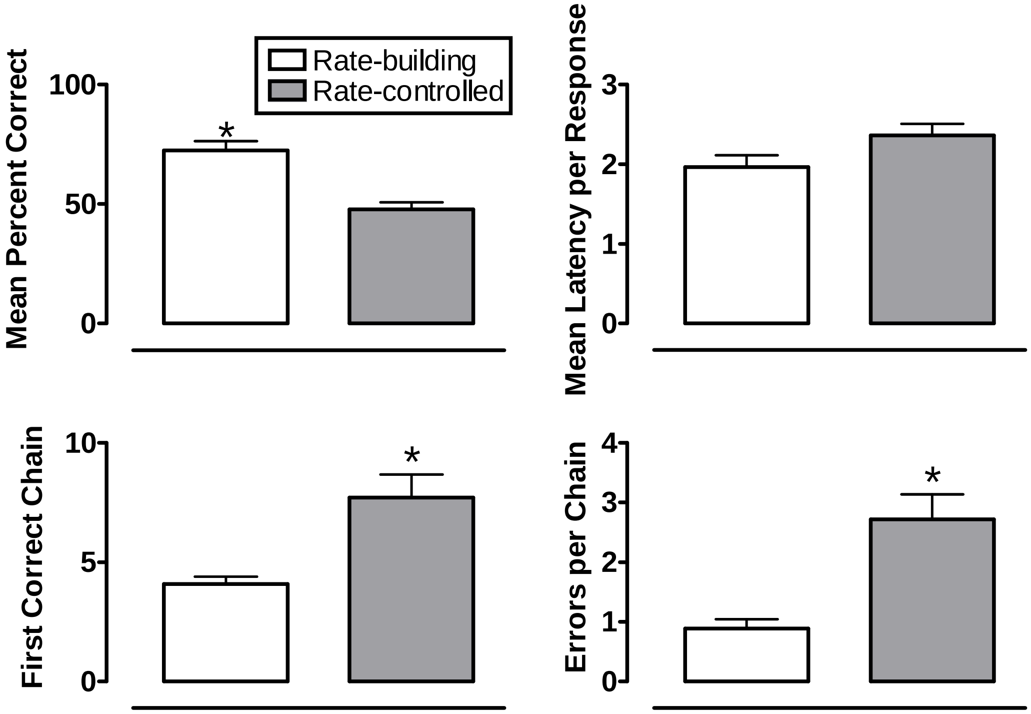


Figure 11. Mean Percent Correct, Latency per Response, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Retention Component across Conditions of Experiment IV with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

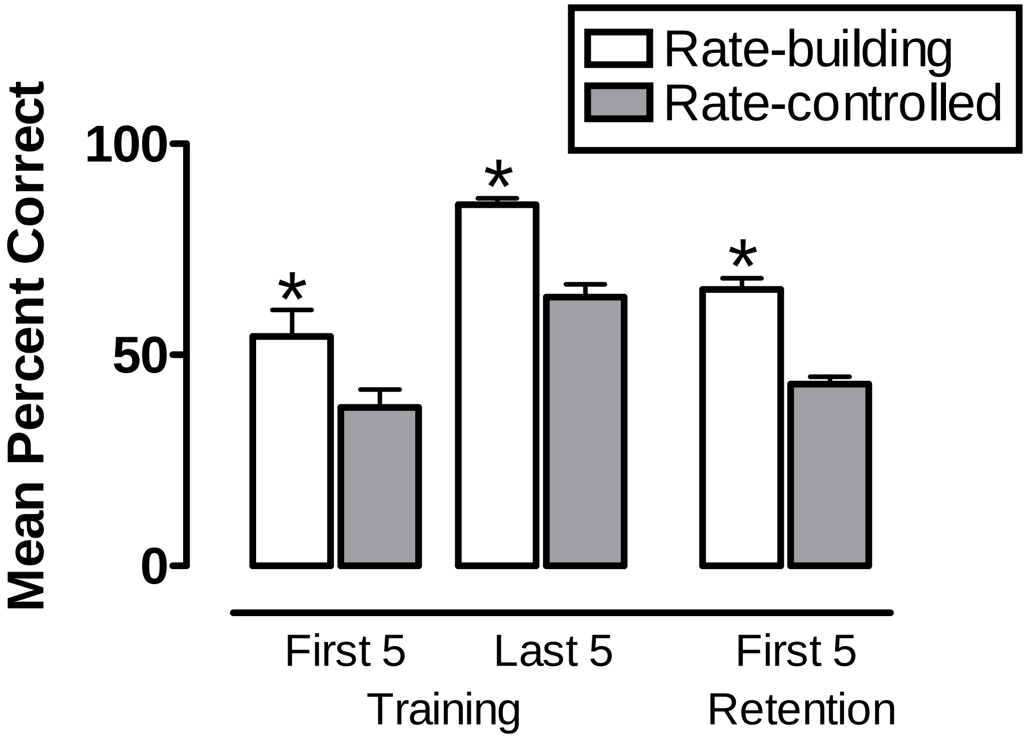


Figure 12. Mean Percent Correct, during First and Last Five Chains during Training and First Five Chains during Retention across Conditions of Experiment IV with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

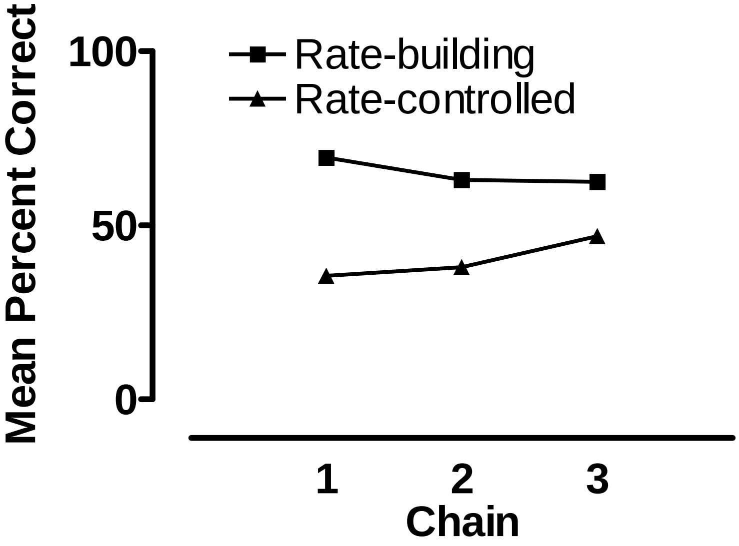


Figure 13. Interaction Plot of Mean Percent Correct, by Chain during Training across Conditions of Experiment IV.

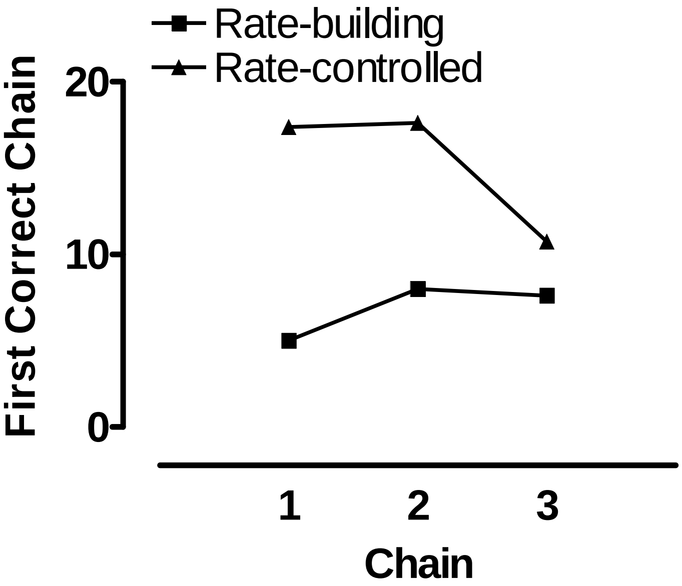


Figure 14. Interaction Plot of First Correct Chain, by Chain during Training across Conditions of Experiment IV.

Table 7

Analysis of Variance Results for Training Component Experiment IV

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	7450.08	7450.08	54.86	0.005
Chain	2	136.29	68.15	0.52	0.617
Subject	3	370.5	123.5		
Condition × Chain	2	675.54	337.77	4.01	0.029
Subject × Condition	3	407.42	135.81		
Subject × Chain	6	780.37	130.06		
Error	30	2527.46	84.25		
Response rate					
Condition	1	1.09048	1.09048	21.34	0.019
Chain	2	0.09846	0.04923	1.39	0.32
Subject	3	0.26688	0.08896		
Condition × Chain	2	0.17839	0.08919	1.41	0.259
Subject × Condition	3	0.15328	0.05109		
Subject × Chain	6	0.21307	0.03551		
Error	30	1.89333	0.06311		
Reinforcement rate					
Condition	1	0.00001001	0.00001001	0.07	0.809
Chain	2	0.00013813	0.00006907	0.7	0.533
Subject	3	0.00024627	0.00008209		
Condition × Chain	2	0.00005159	0.00002579	0.27	0.768
Subject × Condition	3	0.00043095	0.00014365		
Subject × Chain	6	0.00059111	0.00009852		
Error	30	0.00291151	0.00009705		
Latency per response					
Condition	1	4.5881	4.5881	831.33	<0.001
Chain	2	0.0675	0.0337	0.13	0.877
Subject	3	1.569	0.523		
Condition × Chain	2	0.3515	0.1757	1.68	0.203
Subject × Condition	3	0.0166	0.0055		
Subject × Chain	6	1.5138	0.2523		
Error	30	3.1341	0.1045		

Table 7—Continued

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct for first five chains					
Condition	1	3397.2	3397.2	33.21	0.01
Chain	2	35.7	17.9	0.08	0.92
Subject	3	793	264.3		
Condition × Chain	2	137.2	68.6	0.42	0.663
Subject × Condition	3	306.9	102.3		
Subject × Chain	6	1265.7	210.9		
Error	30	4935.3	164.5		
Mean percent correct for last five chains					
Condition	1	5807.5	5807.5	49.84	0.006
Chain	2	694.1	347	2.99	0.126
Subject	3	160.4	53.5		
Condition × Chain	2	112.4	56.2	0.4	0.676
Subject × Condition	3	349.6	116.5		
Subject × Chain	6	696.9	116.2		
Error	30	4246.2	141.5		
First correct chain					
Condition	1	841.69	841.69	62.51	0.004
Chain	2	105.5	52.75	5.46	0.045
Subject	3	83.56	27.85		
Condition × Chain	2	180.5	90.25	3.75	0.035
Subject × Condition	3	40.4	13.47		
Subject × Chain	6	58	9.67		
Error	30	721.17	24.04		

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	32.133	28.021	28.021	58	0.002
Chain	2	0.118	0.146	0.073	0.04	0.962
Subject	3	0.596	0.882	0.294		
Condition × Chain	2	0.049	0.052	0.026	0.01	0.985
Subject × Condition	3	2.231	1.32	0.44		
Subject × Chain	6	11.499	11.499	1.916		
Error	22	38.859	38.859	1.766		

Table 8

Analysis of Variance Results for Retention Component Experiment IV

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	7276.69	7276.69	44.73	0.007
Chain	2	15.29	7.65	0.09	0.919
Subject	3	6.23	2.08		
Condition × Chain	2	115.12	57.56	0.91	0.414
Subject × Condition	3	488.06	162.69		
Subject × Chain	6	538.21	89.7		
Error	30	1898.88	63.3		
Latency per response					
Condition	1	1.8814	1.8814	2.29	0.227
Chain	2	0.6461	0.323	2.2	0.192
Subject	3	11.8118	3.9373		
Condition × Chain	2	0.8153	0.4077	1.64	0.21
Subject × Condition	3	2.4613	0.8204		
Subject × Chain	6	0.8808	0.1468		
Error	30	7.4448	0.2482		
Percent correct in first five chains					
Condition	1	2648.6	2648.6	13.31	0.036
Chain	2	31.43	15.72	0.18	0.841
Subject	3	223.93	74.64		
Condition × Chain	2	369.33	184.67	2	0.153
Subject × Condition	3	596.83	198.94		
Subject × Chain	6	530.43	88.41		
Error	30	2770.26	92.34		
First correct chain					
Condition	1	357.521	357.521	24.81	0.016
Chain	2	57.125	28.563	1.92	0.227
Subject	3	27.063	9.021		
Condition × Chain	2	11.792	5.896	0.64	0.533
Subject × Condition	3	43.229	14.41		
Subject × Chain	6	89.375	14.896		
Error	30	275.208	9.174		

Table 8—Continued

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	149.4433	60.3768	60.3768	56.81	0.002
Chain	2	1.5568	3.7026	1.8513	3.89	0.045
Subject	3	0.9029	2.813	0.9377		
Condition × Chain	2	2.8223	4.4786	2.2393	3.31	0.057
Subject × Condition	3	3.3687	3.5192	1.1731		
Subject × Chain	6	2.4135	2.4135	0.4022		
Error	21	14.2285	14.2285	0.6775		

Discussion

The significant effects of rate-building were clearly demonstrated in Experiment IV by higher mean percent correct during the training and retention components. Subjects displayed faster acquisition and more stable performance during the training and retention tests after rate-building. Retention was demonstrated by increased mean percent correct during the first five chains of retention tests when compared to the first five chains of training. The effect of the retention interval is demonstrated by the decrease in mean percent correct during the first five chains of retention when compared to the last five completed chains of training.

CHAPTER IX

EXPERIMENT V

Purpose

Lindsley (1996) described fluent performance as response-response chaining.

> If songs and poems were simply S-R, S-R, [stimulus-response, stimulus-response] then every word in the series would be the stimulus for the next word…When given any word in the series, one [should be able to] come up with the next word, but most of us cannot do this. We have to go back to a phrase beginning and 'get a running start.' Then we listen as we sing, to hear which word we sing after the questioned word. This looks more like R-R-R-R-R than S-R, S-R, S-R, S-R, S-R. (p. 217)

On this same page, Lindsley discusses a somewhat different conceptualization of response-response chaining and how this may look in a rate-building procedure.

> Recently my experience with workshop practice sheets shows that learners who point to the next item on the sheet learn quicker than learners who do not point…The need to overtly respond to each question is one of the many things that make us think that when a performance becomes fluent it is chained. [The present example] is not merely see-say or S-R. The see must be physically responded to for maximum fluency building. Therefore it is point-see-say, clearly an R-R-R chain. (p. 217)

One can conceptualize fluent performance then in two ways—within each response as a sort of "revealed operant" (Mechner, Hyten, Field, & Madden, 1997) where each question, flash card etc., is answered with a response-response chain, or as a larger chain where each response (each word in the song, each point-see-say) is chained to the next. This conceptualization suggests that rate-building can be arranged by either decreasing latencies for “revealed operants” within each trial or by decreasing latencies between trials, or a combination of both. The effects of rate-building where latencies between trials are decreased may be different than rate-building where latencies between trials are controlled. Arranging spaced trials under this logic would necessarily take a different approach then the previous experiments in that spacing would occur between chains, but not links in the chain. It was the purpose of the current experiment to examine rate-building when latencies between trials are allowed to decrease compared to rate-building when a delay is imposed between chains. Reinforcement rate and number of responses were also be held constant across conditions to examine rate of responding independently.

Method

Six subjects participated in this study (XF, 11407, XD, 13485, 13576, 1224). Conditions were identical to experiment four, with the exception that during the rate-controlled component a 15-s inter-trial interval was arranged and no delay was programmed between links in the chain. As in previous experiments, twelve sessions were conducted with conditions alternating in three-session blocks. After 12 sessions, a non-statistically significant difference was seen between conditions. Consequently, six additional sessions were conducted during which each condition was presented for three consecutive sessions.

Results

Mean percent correct was significantly different across conditions during the training component; however, the interaction between condition and individual chains was also significant. Mean responses per second during the training component of the rate-building condition was significantly higher than during the rate-controlled condition. Additionally, reinforcers per second was significantly higher during the rate-controlled condition. Mean latency was significantly higher during the rate-building condition. Neither dependent measure was significantly different across conditions during the retention component. Figures 15 and 16 represent mean dependent variables for the training and retention components, respectively. Figure 17 presents mean percent correct for the first and last five completed chains during the training component and for the first five completed chains during the retention component by condition. Analysis of variance results are presented in Tables 8 and 10 for the training and retention components, respectively. Significant interactions are plotted in figures 18 and 19 for mean percent correct during training and mean percent correct during the first five chains of training, respectively.

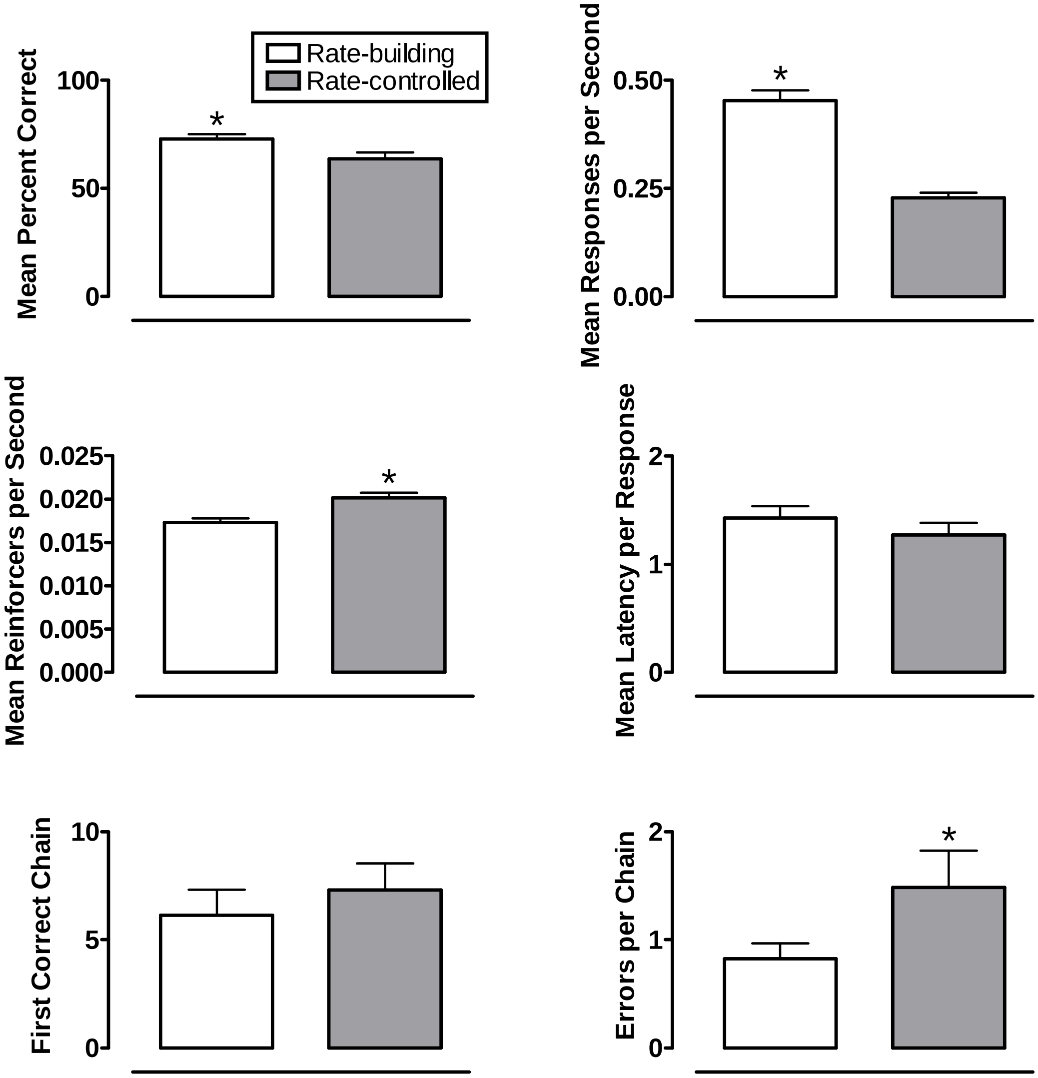


Figure 15. Mean Percent Correct, Response Rate, Reinforcement Rate, Latency per Response, Responses, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Training Component during Each Condition of Experiment V with 95% Confidence Intervals. Significant Differences are marked with Asterisks

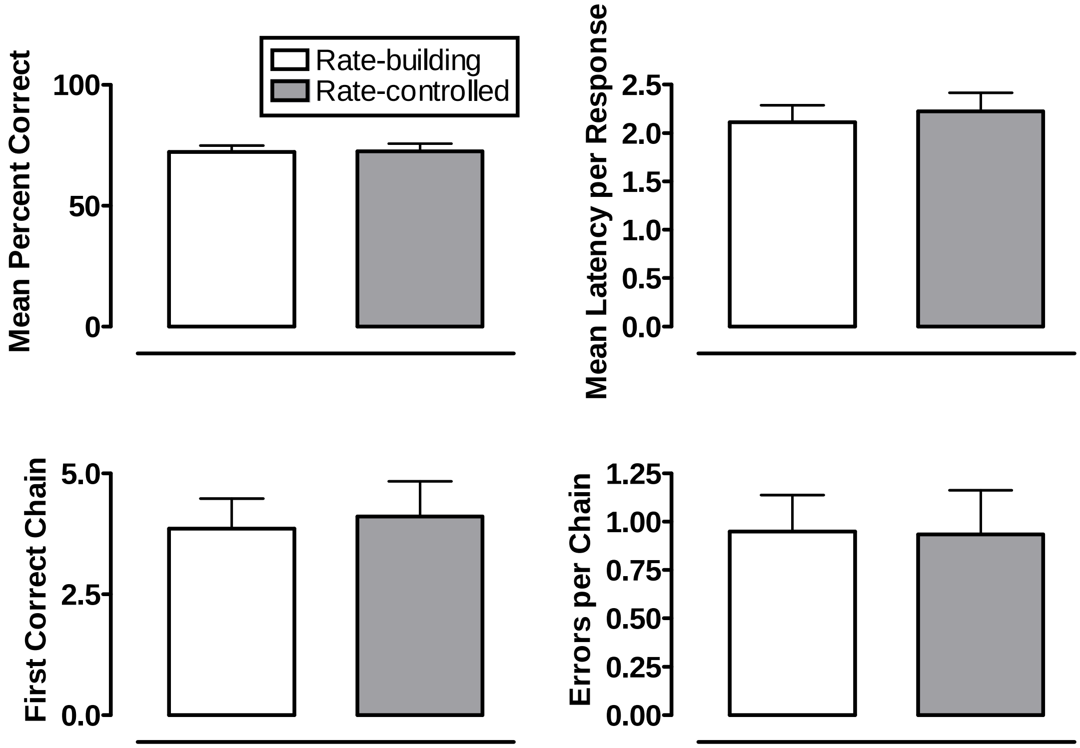


Figure 16. Mean Percent Correct, Latency per Response, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Retention Component across Conditions of Experiment V with 95% Confidence Intervals.

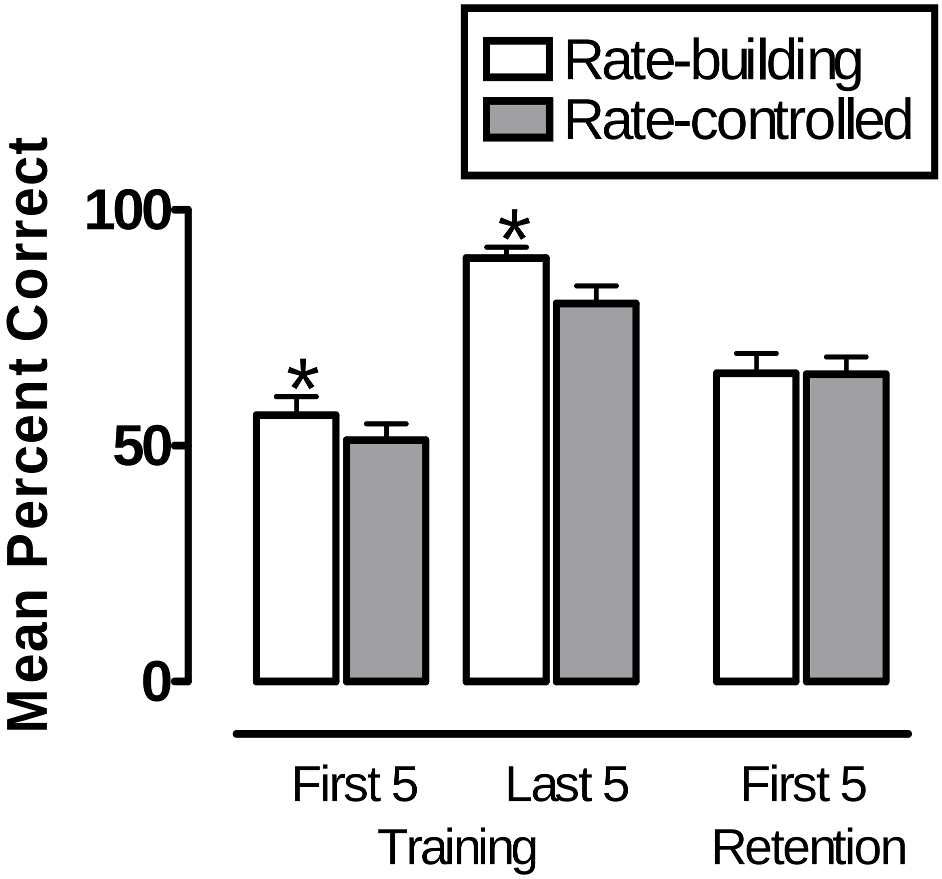


Figure 17. Mean Percent Correct, during First and Last Five Chains during Training and First Five Chains during Retention across Conditions with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

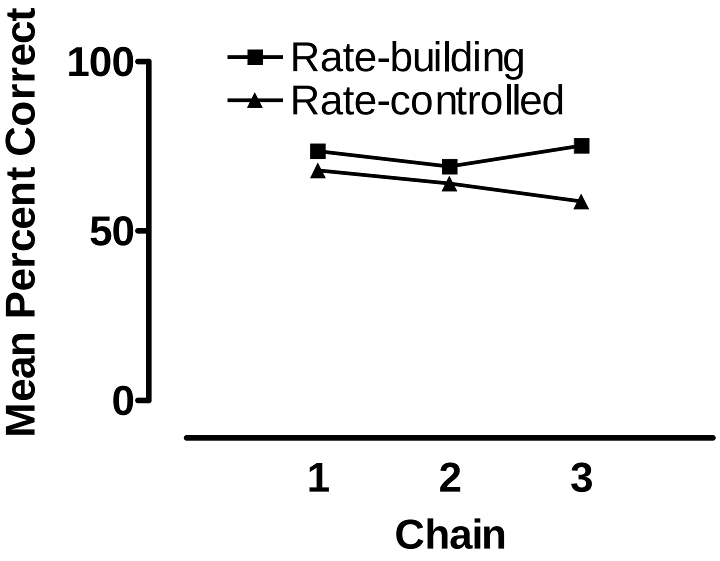


Figure 18. Interaction Plot of Mean Percent Correct, by Chain during Training across Conditions of Experiment V.

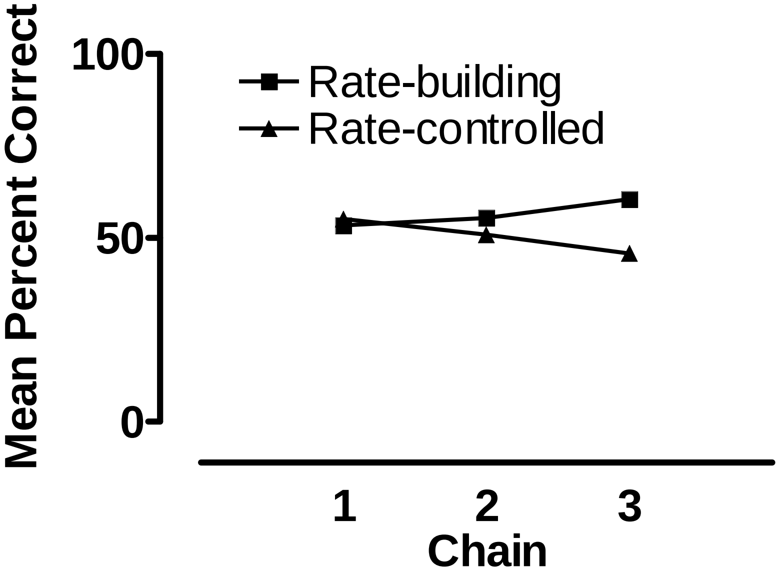


Figure 19. Interaction Plot of Mean Percent Correct in First Five Chains, by Chain during Training across Conditions of Experiment V.

Table 9

Analysis of Variance Results for Training Component Experiment V

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	2241.33	2241.33	29.87	0.003
Chain	2	386.72	193.36	2.85	0.105
Subject	5	1575.89	315.18		
Condition × Chain	2	739.39	369.69	5.18	0.008
Subject × Condition	5	375.22	75.04		
Subject × Chain	10	679.06	67.91		
Error	82	5847.06	71.31		
Response rate					
Condition	1	1.37983	1.37983	292.28	<0.001
Chain	2	0.026543	0.013271	3.44	0.073
Subject	5	0.032399	0.00648		
Condition × Chain	2	0.001359	0.00068	0.16	0.854
Subject × Condition	5	0.023605	0.004721		
Subject × Chain	10	0.03854	0.003854		
Error	82	0.352173	0.004295		
Reinforcement rate					
Condition	1	2.12E-04	2.12E-04	35.15	0.002
Chain	2	1.40E-05	7.01E-06	1.03	0.391
Subject	5	3.62E-05	7.24E-06		
Condition × Chain	2	7.35E-06	3.68E-06	1.19	0.309
Subject × Condition	5	3.01E-05	6.03E-06		
Subject × Chain	10	6.79E-05	6.79E-06		
Error	82	2.53E-04	3.08E-06		
Latency per trial					
Condition	1	0.6095	0.6095	1.27	0.311
Chain	2	0.6707	0.3353	4.58	0.039
Subject	5	3.8813	0.7763		
Condition × Chain	2	0.0234	0.0117	0.1	0.902
Subject × Condition	5	2.3988	0.4798		
Subject × Chain	10	0.732	0.0732		
Error	82	9.2626	0.113		

Table 9—Continued

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct for first five chains					
Condition	1	926.7	926.7	11.38	0.02
Chain	2	30.4	15.2	0.1	0.903
Subject	5	4001	800.2		
Condition × Chain	2	1238	619	4.85	0.01
Subject × Condition	5	407.3	81.5		
Subject × Chain	10	1475.4	147.5		
Error	82	10458.7	127.5		
Mean percent correct for last five chains					
Condition	1	2504.1	2504.1	16.47	0.01
Chain	2	236.2	118.1	0.66	0.537
Subject	5	340.5	68.1		
Condition × Chain	2	8.5	4.3	0.04	0.963
Subject × Condition	5	760.4	152.1		
Subject × Chain	10	1781.7	178.2		
Error	82	9358	114.1		
First correct chain					
Condition	1	50.7	50.7	3.88	0.106
Chain	2	83.35	41.68	1.27	0.324
Subject	5	209.85	41.97		
Condition × Chain	2	0.57	0.29	0.02	0.979
Subject × Condition	5	65.41	13.08		
Subject × Chain	10	329.43	32.94		
Error	82	1125.31	13.72		

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	11.2275	11.3505	11.3505	19.02	0.007
Chain	2	1.9871	2.2463	1.1231	1.85	0.206
Subject	5	5.1499	4.8041	0.9608		
Condition × Chain	2	3.1381	3.0606	1.5303	1.89	0.158
Subject × Condition	5	3.2798	2.9696	0.5939		
Subject × Chain	10	6.0533	6.0533	0.6053		
Error	73	59.1292	59.1292	0.81		

Table 10

Analysis of Variance Results for Retention Component Experiment V

Source	*df*	*SS*	*MS*	*F*	*p*
Mean percent correct					
Condition	1	11.02	11.02	0.06	0.822
Chain	2	1120.92	560.46	3.65	0.065
Subject	5	242.46	48.49		
Condition × Chain	2	106.93	53.47	0.59	0.557
Subject × Condition	5	985.99	197.2		
Subject × Chain	10	1535.8	153.58		
Error	82	7444.85	90.79		
Latency per trial					
Condition	1	0.267	0.267	5.84	0.06
Chain	2	1.8563	0.9282	2.23	0.158
Subject	5	13.0224	2.6045		
Condition × Chain	2	2.0127	1.0064	3.36	0.04
Subject × Condition	5	0.2284	0.0457		
Subject × Chain	10	4.1545	0.4154		
Error	82	24.5924	0.2999		
Mean percent correct in first five chains					
Condition	1	0.4	0.4	0	0.968
Chain	2	2297	1148.5	3.99	0.053
Subject	5	2323.1	464.6		
Condition × Chain	2	137.5	68.8	0.45	0.637
Subject × Condition	5	1017.9	203.6		
Subject × Chain	10	2875.3	287.5		
Error	82	12421.7	151.5		
First correct chain					
Condition	1	1.815	1.815	0.41	0.552
Chain	2	120.241	60.12	9.04	0.006
Subject	5	20.519	4.104		
Condition × Chain	2	0.907	0.454	0.09	0.917
Subject × Condition	5	22.296	4.459		
Subject × Chain	10	66.537	6.654		
Error	82	427.648	5.215		

Table 10—Continued

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	0.0845	0.0753	0.0753	0.37	0.57
Chain	2	8.0894	7.8943	3.9472	5.24	0.028
Subject	5	5.8264	5.8437	1.1687		
Condition × Chain	2	0.9971	1.0022	0.5011	1.07	0.348
Subject × Condition	5	1.0357	1.0187	0.2037		
Subject × Chain	10	7.5397	7.5397	0.754		
Error	81	37.9795	37.9795	0.4689		

An additional comparison was made between the rate-controlled conditions of Experiment 4 and Experiment 5. The sessions during the two conditions were programmed to have identical total delay per chain (15 s), with the delays occurring mostly within the chain during experiment four, and between chains during experiment five. Reinforcement was delivered under identical VI schedules during both conditions. Subjects that did not participate in both studies (13576, 1224) were removed from the statistical analysis, which was conducted by means of a general linear model analysis of variance due to an unbalanced design. Mean accuracy during the training component was significantly higher during the rate-controlled condition of Experiment 5; however, the interaction between conditions and chains was again significant.

Mean latency per response was significantly lower during Experiment 5. Mean responses, rate of reinforcement, and rate of responding was equivalent across conditions. Mean percent correct was significantly higher during Experiment 5. Figures 20 and 21 display dependent variables for the rate-controlled conditions of Experiments 4 and 5 during the training and retention components, respectively.

Figure 22 presents mean percent correct for the first and last five chains completed during the training component and the first five chains completed during the retention component by condition. Tables 11 and 12 list the results of general linear model analysis of variance for each dependent variable for the training and retention components, respectively. The interaction plot for mean percent correct during training is presented in figure 23.

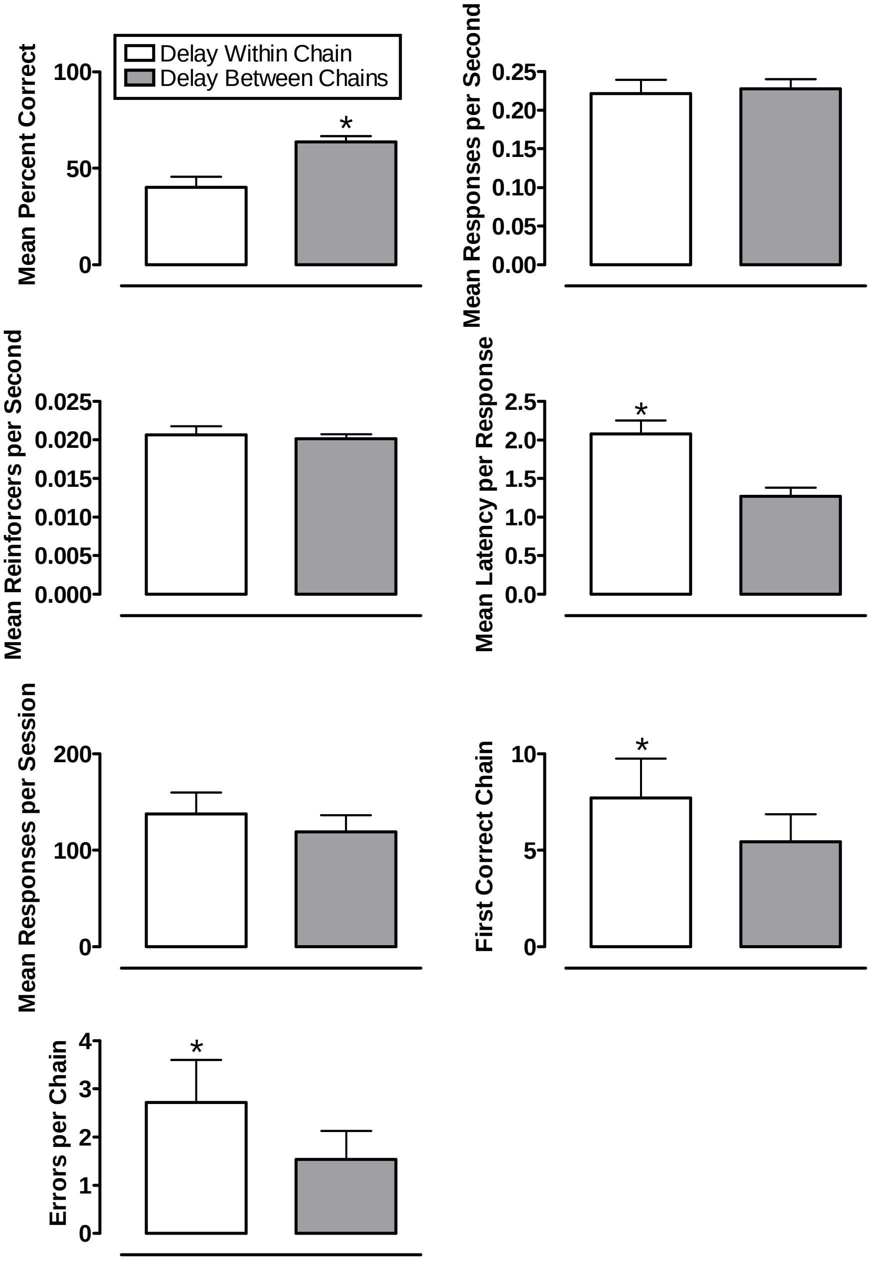


Figure 20. Mean Percent Correct, Response Rate, Reinforcement Rate, Responses, Latency per Response, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Training Component during Rate-controlled Conditions of Experiments IV and V with 95% Confidence Intervals. Significant Differences are marked with Asterisks

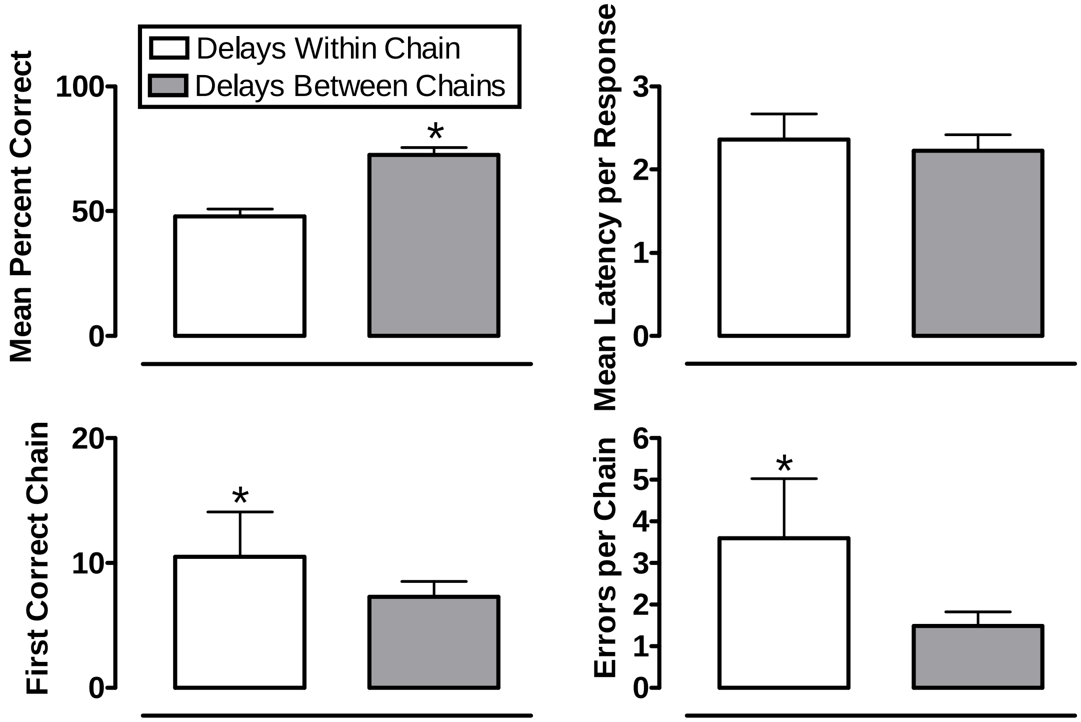


Figure 21. Mean Percent Correct, Latency per Response, First Chain without Errors, and Errors per Chain after First Chain without Errors for the Retention Component during Rate-controlled Conditions with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

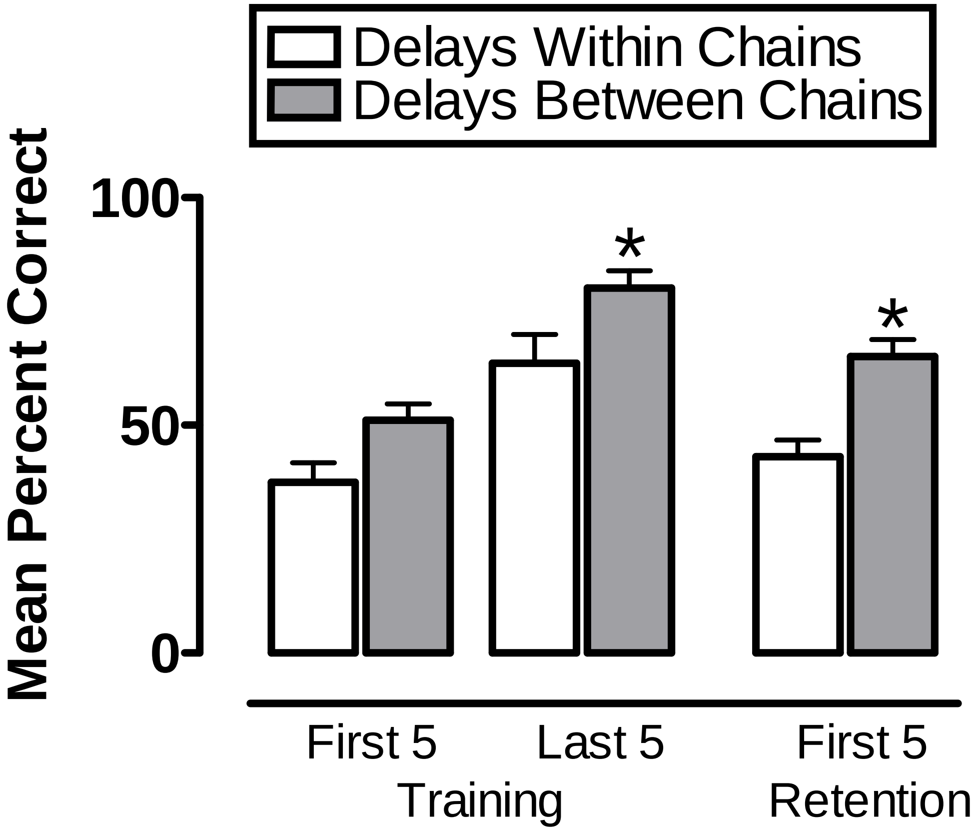


Figure 22. Mean Percent Correct during First and Last Five Chains during Training and First Five Chains during Retention Components of Each Rate-controlled Condition for Experiments IV and V with 95% Confidence Intervals. Significant Differences are Marked with Asterisks.

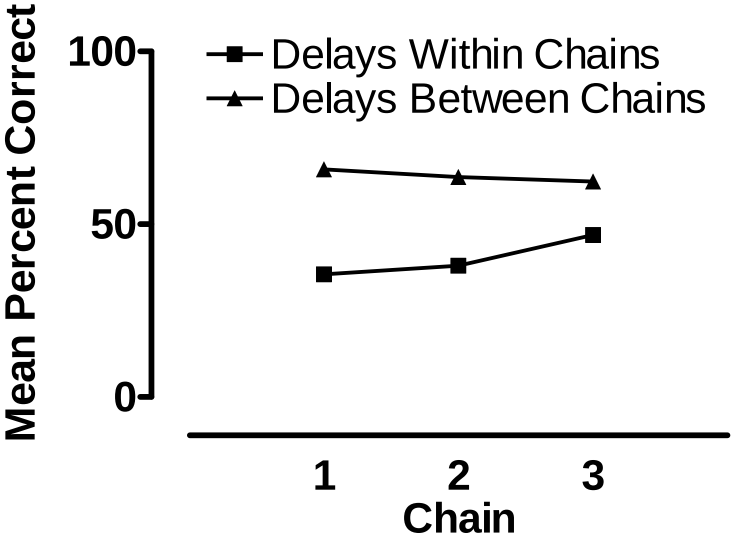


Figure 23. Interaction Plot of Mean Percent Correct, by Chain during Training across Rate-controlled Conditions of Experiments IV and V.

Table 11

Analysis of Variance Results for Training Component during Rate-controlled Conditions of Experiments IV and V

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
			Mean percent correct			
Condition	1	8189.14	8189.14	8189.14	48.18	0.006
Chain	2	89.63	188.24	94.12	0.49	0.634
Subject	3	1197.93	1157.34	385.78		
Condition × Chain	2	560.84	560.84	280.42	3.24	0.049
Subject × Condition	3	509.94	509.94	169.98		
Subject × Chain	6	1178.77	1178.77	196.46		
Error	42	3640.48	3640.48	86.68		
			Response rate			
Condition	1	0.001382	0.001382	0.001382	0.4	0.572
Chain	2	0.000473	0.00041	0.000205	0.12	0.887
Subject	3	0.004428	0.005338	0.001779		
Condition × Chain	2	0.01477	0.01477	0.007385	4.91	0.012
Subject × Condition	3	0.010341	0.010341	0.003447		
Subject × Chain	6	0.010152	0.010152	0.001692		
Error	42	0.063197	0.063197	0.001505		
			Reinforcement rate			
Condition	1	0.0000077	0.0000077	0.0000077	5.6	0.099
Chain	2	0.000001	0.0000008	0.0000004	0.37	0.707
Subject	3	0.0000028	0.0000018	0.0000006		
Condition × Chain	2	0.0000002	0.0000002	0.0000001	0.1	0.909
Subject × Condition	3	0.0000041	0.0000041	0.0000014		
Subject × Chain	6	0.0000064	0.0000064	0.0000011		
Error	42	0.000049	0.000049	0.0000012		
			Latency per trial			
Condition	1	11.9559	11.9559	11.9559	56.74	0.005
Chain	2	0.0196	0.0557	0.0279	0.18	0.839
Subject	3	2.1277	1.9333	0.6444		
Condition × Chain	2	0.5005	0.5005	0.2502	2.07	0.139
Subject × Condition	3	0.6322	0.6322	0.2107		
Subject × Chain	6	0.9372	0.9372	0.1562		
Error	42	5.0872	5.0872	0.1211		

Table 11—Continued

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Mean percent correct in first five chains						
Condition	1	2613.47	2613.47	2613.47	8.04	0.066
Chain	2	220.8	172.87	86.44	0.8	0.49
Subject	3	1193.49	952.86	317.62		
Condition × Chain	2	321.55	321.55	160.77	1.78	0.182
Subject × Condition	3	974.82	974.82	324.94		
Subject × Chain	6	654.35	654.35	109.06		
Error	42	3802.36	3802.36	90.53		
Mean percent correct in last five chains						
Condition	1	3492.6	3492.6	3492.6	36.87	0.009
Chain	2	867	947.5	473.7	2.5	0.156
Subject	3	829.6	797	265.7		
Condition × Chain	2	95.7	95.7	47.8	0.23	0.797
Subject × Condition	3	284.2	284.2	94.7		
Subject × Chain	6	1130.8	1130.8	188.5		
Error	42	8782.2	8782.2	209.1		
First correct chain						
Condition	1	877.34	877.34	877.34	21.63	0.019
Chain	2	165.23	210.21	105.1	4.8	0.052
Subject	3	89.13	92.1	30.7		
Condition × Chain	2	96.41	96.41	48.2	2.14	0.13
Subject × Condition	3	121.7	121.7	40.57		
Subject × Chain	6	131.17	131.17	21.86		
Error	42	945.75	945.75	22.52		
Errors per chain after first correct chain						
Condition	1	15.837	14.378	14.378	10.63	0.04
Chain	2	0.696	0.402	0.201	0.07	0.934
Subject	3	4.703	1.726	0.575		
Condition × Chain	2	0.326	0.598	0.299	0.14	0.871
Subject × Condition	3	3.414	3.971	1.324		
Subject × Chain	6	18.489	18.489	3.081		
Error	33	70.912	70.912	2.149		

Table 12

Analysis of Variance Results for Retention Component during Rate-controlled Conditions of Experiments IV and V

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Mean percent correct						
Condition	1	9776.04	9776.04	9776.04	77.47	0.003
Chain	2	203.43	159.11	79.55	0.5	0.628
Subject	3	387.25	335.22	111.74		
Condition × Chain	2	226.84	226.84	113.42	1.28	0.29
Subject × Condition	3	378.56	378.56	126.19		
Subject × Chain	6	967.88	967.88	161.31		
Error	42	3734.36	3734.36	88.91		
Latency per trial						
Condition	1	0.1069	0.1069	0.1069	0.21	0.678
Chain	2	1.3363	1.2096	0.6048	3.69	0.08
Subject	3	14.5098	15.2606	5.0869		
Condition × Chain	2	0.1126	0.1126	0.0563	0.17	0.844
Subject × Condition	3	1.526	1.526	0.5087		
Subject × Chain	6	0.9429	0.9429	0.1572		
Error	42	13.8757	13.8757	0.3304		
Mean percent correct in first five chains						
Condition	1	8229.5	8229.5	8229.5	81.44	0.003
Chain	2	637.7	413.8	206.9	0.71	0.53
Subject	3	470.3	353.5	117.8		
Condition × Chain	2	1097.2	1097.2	548.6	5.23	0.009
Subject × Condition	3	303.2	303.2	101.1		
Subject × Chain	6	1806.7	1806.7	301.1		
Error	42	4402.5	4402.5	104.8		
First correct chain						
Condition	1	424.67	424.67	424.67	67.9	0.004
Chain	2	104.43	103.82	51.91	3.22	0.108
Subject	3	55.25	64.63	21.54		
Condition × Chain	2	19.29	19.29	9.64	0.9	0.412
Subject × Condition	3	18.76	18.76	6.25		
Subject × Chain	6	98.1	98.1	16.35		
Error	42	447.68	447.68	10.66		

Table 12—Continued

Source	*df*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*p*
Errors per chain after first correct chain						
Condition	1	55.075	14.946	14.946	7	0.042
Chain	2	4.38	3.796	1.898	1.59	0.22
Subject	3	3.02	6.177	2.059		
Condition × Chain	2	2.764	3.13	1.565	0.8	0.459
Subject × Condition	3	8.225	6.628	2.209		
Subject × Chain	6	3.313	3.313	0.552		
Error	28	54.69	54.69	1.953		

Discussion

In this experiment retention did not differ significantly across conditions, but overall rate of responding strongly affected accuracy during training the components. Rate-building by allowing latencies between chains to decrease produced significantly enhanced mean percent correct and endurance during training when compared to rate-building when delays were imposed between chains (rate-controlled condition). The comparison between the rate-controlled conditions of Experiments 4 and 5 demonstrated that allowing responding within chains to occur without delay significantly increased performance measures when compared to chains where links were delayed, despite identical overall response and reinforcement rates.

CHAPTER X

EXPERIMENT VI

Purpose

It may be argued that imposing a delay between links of the chain caused a general disruption in performance, therefore, the effects of this manipulation were not due to differing rates of response but rather the disruption caused by imposing the delay. If this is the case, habituation should develop with repeated exposure to the delay condition and accuracies should return to levels similar to those during the non-delayed conditions. Experiment 6 explored this possibility.

Method

Two subjects (13576, 1224) participated in this experiment. Nine consecutive sessions identical to those from Experiment 4 were conducted, with the exception that 5-s delays were imposed between links in the chain and a 5-s inter-trial interval occurred during all three components (retention test, distracter, and training). Each session ended after 200 responses occurred during the training component. After nine sessions, the delays and inter-trial intervals were removed in all components and subjects were trained for 9 additional sessions.

Results

Mean percent correct during the training component for each session and regression lines are presented by subject in Figure 19. An intervention analysis was used to calculate whether the level or trend change of regression lines for accuracy during the training component was significant from one condition to the next (McKnight, McKeen, & Huitema, 2000). Results from this analysis are listed in Table 13. Neither statistic was significant for subject two, while the slope-change from rate-controlled to rate-building conditions was significant for subject one. Subject two required six additional sessions of rate-building condition after the study concluded to return to baseline accuracy.

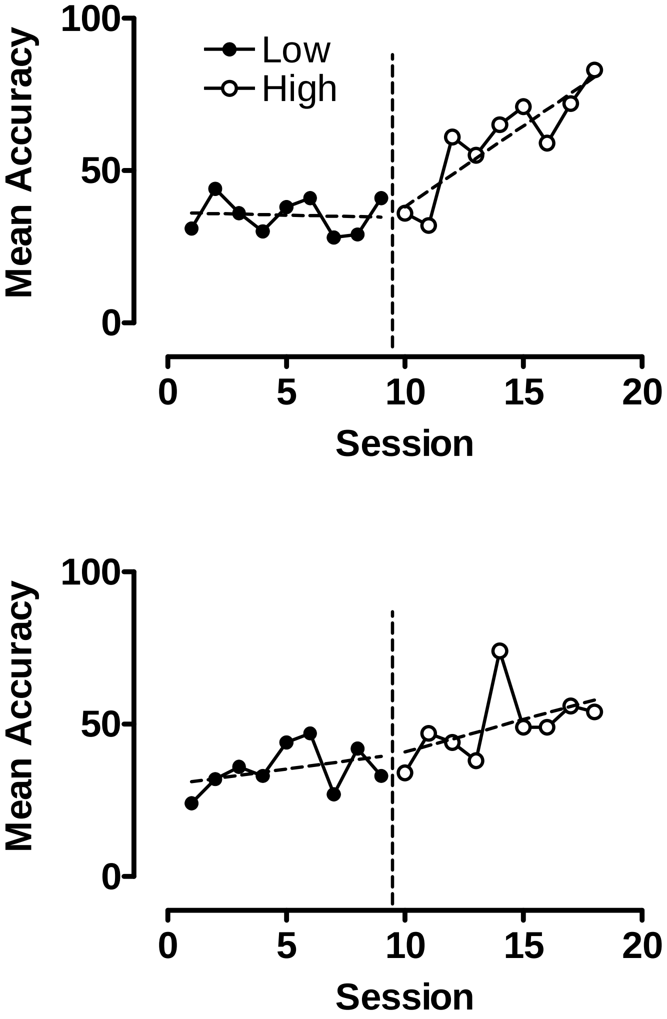


Figure 24. Mean Percent Correct for Training Component by Session and Condition for Subjects One and Two Experiment VI. Linear Regression Lines are Represented for each Condition.

Table 13

Intervention Analysis Results for Percent Correct Measures Experiment VI

Factor	*T*	*p*
	Bird 1	
Level change	-0.108	0.916
Slope change	3.257	0.006
	Bird 2	
Level change	0.089	0.930
Slope change	1.019	0.327

Discussion

The pervasive effects of intentionally slowed responding are clearly demonstrated in the performances of the two subjects. The non-significant slope change for the second subject and the subsequent prolonged retraining necessary demonstrate that learning impaired by spaced responding can disrupt future performance when trials are presented in a massed fashion. This evidence strongly suggests that allowing students to respond “as fast as you can” produces enhanced learning outcomes.

CHAPTER XI

GENERAL DISCUSSION

As reported by Doughty et al. (2004), all but three of the 48 studies examining the effects of rate-building procedures are confounded by at least one of two variables: rate of reinforcement or number of trials. The presence of these confounds and the mixed results of the adequately controlled studies (Evans, Mercer, & Evans, 1983; Evans & Evans, 1985; Shirley & Pennypacker, 1994) casts some doubt on the Precision Teachers' claim that building high rates of performance alone results in the enhanced performance typically seen with such procedures. The current studies effectively controlled for the effects of reinforcement rate and trials across rate-building and rate-controlled conditions and examined the effects of reinforcement rate and number of trials in separate experiments. Controlling these variables across rate-building and rate-controlled conditions allowed a valid appraisal of the effects of increased response rates *per se* on learning.

In these experiments, rate-building procedures produced fast, accurate responding. This effect was seen when reinforcement rates and number of responses allowed were equivalent across high and low-rate conditions, suggesting that response rate was the primary variable affecting performance. In two experiments in which rate of responding was the independent variable (Experiments 1 and 4), performance at the 23-h retention test displayed not only greater endurance (fewer errors per chain subsequent to first chain without an error) but also faster acquisition of performance. Faster acquisition was also seen during the training components of these experiments and of Experiment 5. The present findings suggest that rate-building positively affects retention, endurance, and speed of acquisition. Rate of reinforcement, although an important variable in other learning preparations (e.g., Dube & McIlvane, 2002), produced no detectable effect on learning measures during the present studies. This may be because the current research used different measures of performance and the previous research did not test for response strength in the same manner.

The results of the present studies suggest that although overall rate of responding is clearly related to retention, acquisition, and endurance of discriminated responding, how rates are manipulated significantly affects the influence of this variable. When low rates of responding were arranged by delaying responses within chains, all learning measures were impaired relative to arrangements without delays. However, when low rates of responding were arranged by placing delays between chains, only training measures were affected, and this impairment was significantly less than when delays were arranged within chains. The important difference between the two low rate of responding conditions was that when delays were placed between chains, responding was allowed to occur relatively fast within chains.

It is important to note that due to species differences, the results of this study may not be wholly or directly applicable to human behavior. The unique abilities of relational responding and related verbal behavior present in human repertoires are not represented in this research; therefore, similar studies with humans are warranted. It is also possible that the level of the establishing operation (food deprivation) used in present studies affected responding. If motivation levels are high, as they appeared to be in the present study, forcing slow responding may cause learning impairments. Alternatively, high motivation levels may be necessary for high rates of responding to enhance learning. It is interesting that Precision Teachers engage in a variety of activities that appear to serve as establishing operations (EOs) for the consequences of students' correct responding (Binder, 1996; Doughty et al., 2004), and it may well be that these EOs are at least partially responsible for the beneficial effects of rate-building that they report.

The Role of Conditioned Reinforcement

A potential uncontrolled confound may exist in the present experiments that were intended to compare rate-building to rate-controlled procedures. As response rates increased in the rate-building procedures, so did the rates of completed chains and chain links. If progressing through schedule components (links in the chain) functioned as conditioned reinforcement, rates of this conditioned reinforcement would have been higher during rate-building. This variable may have contributed to the enhanced learning during rate-building conditions. However, a brief examination of value and function of conditioned reinforcement in similar experimental preparations makes this possibility very unlikely.

Progressing through each chain may be thought of as completing a single response (e.g., a math problem) in a rate-building procedure. The first link may be the first movement in the response (e.g., orient to the problem), the second link the second movement (e.g., read the problem), the third link the third response (e.g., write the answer). However oversimplified this may be, the stimuli associated with responding appropriately for each movement, or moving through each link in the chain, may take on reinforcing properties as these stimuli are paired with primary or previously established conditioned reinforcement. It is reasonable to assume that the reinforcing properties of these stimuli are directly related to the schedule of primary reinforcement, and there are three popular theories which attempt to describe the value or ability of conditioned stimuli to control behavior: delay-reduction theory (DRT) (Squires & Fantino, 1971), the contextual choice model (CCM) (Grace, 1994), and the hyperbolic value-added model (HVA) (Mazur, 2001).

Each of these theories, when applied to the current experiments, predicts that although conditioned stimuli (progressing through the chain) occurred at a higher rate during rate-building conditions, the ability of these stimuli to control responding would have been equivalent across conditions. The value of progressing through the chain during rate-controlled conditions would have been much higher than the value of progressing through rate-building chains due to higher associations with frequency of primary reinforcement (CCM and HVA), and increased reduction in delay to reinforcement (DRT and HVA).

Additionally, recent research examining the ability of conditioned reinforcement to produce responding that is resistant to disruption (Shahan & Podlesnik, 2005) suggests that elevated rates of stimuli that function as conditioned reinforcement do not affect behavioral momentum when rates of primary reinforcement are held constant across conditions. These findings suggest that even if rates of conditioned reinforcement were elevated during the rate-building conditions, the development of response strength due to conditioned reinforcement was equivalent across conditions because rates of primary reinforcement were equivalent across rate-building and rate-controlled conditions.

Applied Implications

The current research supports the hypothesis that building high rates of responding leads to enhanced retention, endurance, and accuracy. In addition, acquisition of discriminated responding appears to be similarly affected. Specifically, this research supports rate-building as practiced by Precision Teachers, where latencies within each trial and latencies between trials are reduced through training.

It is important to note that Precision Teaching is somewhat different than more traditional teaching methods when student motivation is considered. Precision Teachers increase effectiveness of consequences for fast accurate performance by “hustling” or “cheering” students. This manipulation of establishing operations (Laraway, Synerski, Michael, & Poling, 2003) is necessary for decreased latencies and ultimately higher rates of performance. Due to food deprivation, conditions during the present study were more similar to this scenario than a traditional setting where such motivating operations are not manipulated to this degree.

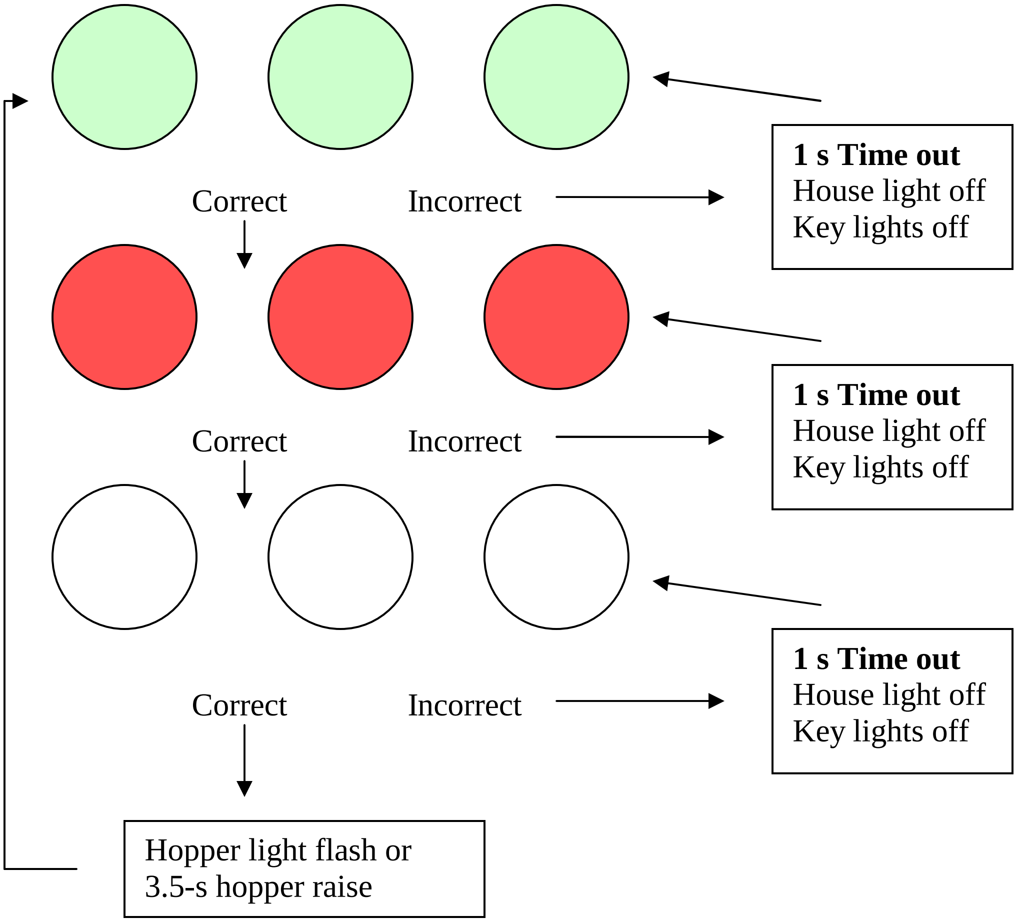
Taken together, the results suggest that instructional programs should be concerned with motivating students to perform high rates of learned responses, and that those responses should be trained repeatedly in a manner similar to the one-minute timings used by Precision Teachers.

Future Research

The present research could be expanded in several ways. First, each of the experiments measured the effects of acquisition and practice of response sequences under each condition. This is somewhat different from learning and rate-building as arranged in educational settings, because in these settings acquisition normally occurs at the same rate, then responses are practiced at high or low rates to show the effects of rate-building. Future studies could first train response sequences to an acquisition criterion, then allow for slow or fast practice while yoking rates of reinforcement and number of responses across conditions. Second, a single delay value was studied during these experiments (5 s). It is reasonable to suppose that the degree of delay between responses may have a direct relationship with performance. Future studies could compare different delay values to determine if this is the case. Third, the current series of studies did not examine two of the most important products of training to fluency: application and adduction. Future studies could arrange such tests. Fourth, the measurement of endurance during the experiments differed from techniques commonly used in studies of behavioral momentum (Nevin, 1992; Nevin et al., 2003). To provide a more similar comparison, disruption typically used when resistance to change is studied (response-independent food presentation, prefeeding) could be used to assess endurance. Fifth, Dube and McIlvane (2002), found effects of reinforcement rate on the persistence of conditional discriminations; this effect was not found during these studies (Experiments 2 and 3). However, it is important to note that Dube and McIlvane tested for persistence by reversing the discriminations whereas during the current study persistence was tested by acquisition, endurance, and retention measures. Future studies could test persistence of conditional discrimination in the current procedure by changing the required response sequence. Finally, the current studies generally used a single fluency criterion for determining training length. Precision Teachers constantly revise and test lengths and arrangements of training to determine the best, most widely applicable fluency aim for any one skill. Future studies could examine training of different lengths and arrangements to determine if learning outcomes could be enhanced.

Appendix A

Repeated Acquisition Procedural Outline


Correct
Incorrect
1 s Time out
House light off
Key lights off
Correct
Incorrect
1 s Time out
House light off
Key lights off
Correct
Incorrect
1 s Time out
House light off
Key lights off
Hopper light flash or
3.5-s hopper raise

Appendix B

Arrangement of Sessions for Each Experiment

Arrangement of Sessions Experiment I

Component	Condition	Chain	Ends After
Day One (High)			
Retention	None	1	3 bins
Training	None	2	4 bins under 45 s
Day Two (High)			
Retention	None	2	3 bins
Training	None	3	4 bins under 45 s
Day Three (High)			
Retention	None	3	3 bins
Training	None	1	4 bins under 45 s
Day Four (Low)			
Retention	None	1	3 bins
Training	5 s delay between links	2	Yoked responses
Day Five (Low)			
Retention	None	2	3 bins
Training	5 s delay between links	3	Yoked responses
Day Six (Low)			
Retention	None	3	3 bins
Training	5 s delay between links	1	Yoked responses
Conditions Repeat			

Arrangement of Sessions Experiment II

Component	Condition	Chain	Ends After
	Day One (High)		
Retention	None	1	3 bins
Training	FR 3	2	4 bins under 45 s
	Day Two (High)		
Retention	None	2	3 bins
Training	FR 3	3	4 bins under 45 s
	Day Three (High)		
Retention	None	3	3 bins
Training	FR 3	1	4 bins under 45 s
	Day Four (Low)		
Retention	None	1	3 bins
Training	FR 6	2	4 bins under 45 s
	Day Five (Low)		
Retention	None	2	3 bins
Training	FR 6	3	4 bins under 45 s
	Day Six (Low)		
Retention	None	3	3 bins
Training	FR 6	1	4 bins under 45 s
	Conditions Repeat		

Arrangement of Sessions Experiment III

Component	Condition	Chain	Ends After
	Day One (High)		
Retention	VI 50 s	1	3 bins
Distracter	VI 50 s	4	20 bins
Training	VI 40 s	2	120 responses
	Day Two (High)		
Retention	VI 50 s	2	3 bins
Distracter	VI 50 s	5	20 bins
Training	VI 40 s	3	120 responses
	Day Three (High)		
Retention	VI 50 s	3	3 bins
Distracter	VI 50 s	6	20 bins
Training	VI 40 s	1	120 responses
	Day Four (Low)		
Retention	VI 50 s	1	3 bins
Distracter	VI 50 s	4	20 bins
Training	VI 60 s	2	120 responses

Arrangement of Sessions Experiment III —Continued

Day Five (Low)			
Retention	VI 50 s	2	3 bins
Distracter	VI 50 s	5	20 bins
Training	VI 60 s	3	120 responses
Day Six (Low)			
Retention	VI 50 s	3	3 bins
Distracter	VI 50 s	6	20 bins
Training	VI 60 s	1	120 responses
Conditions Repeat			

Arrangement of Sessions Experiment IV

Component	Condition	Chain	Ends After
	Day One (High)		
Retention	None	1	3 bins
Distracter	None	4	20 bins
Training	None	2	4 bins under 45 s
	Day Two (High)		
Retention	None	2	3 bins
Distracter	None	5	20 bins
Training	None	3	4 bins under 45 s
	Day Three (High)		
Retention	None	3	3 bins
Distracter	None	6	20 bins
Training	None	1	4 bins under 45 s
	Day Four (Low)		
Retention	None	1	3 bins
Distracter	None	4	20 bins
Training	5 s delays between links	2	Yoked responses

Arrangement of Sessions Experiment IV —Continued

Day Five (Low)			
Retention	None	2	3 bins
Distracter	None	5	20 bins
Training	5 s delays between links	3	Yoked responses
Day Six (Low)			
Retention	None	3	3 bins
Distracter	None	6	20 bins
Training	5 s delays between links	1	Yoked responses
Conditions Repeat			

Arrangement of Sessions Experiment V

Component	Condition	Chain	Ends After
Day One (High)			
Retention	None	1	3 bins
Distracter	None	4	20 bins
Training	None	2	4 bins under 45 s
Day Two (High)			
Retention	None	2	3 bins
Distracter	None	5	20 bins
Training	None	3	4 bins under 45 s
Day Three (High)			
Retention	None	3	3 bins
Distracter	None	6	20 bins
Training	None	1	4 bins under 45 s
Day Four (Low)			
Retention	None	1	3 bins
Distracter	None	4	20 bins
Training	15 s delay between chains	2	Yoked responses

Arrangement of Sessions Experiment V —Continued

Day Five (Low)			
Retention	None	2	3 bins
Distracter	None	5	20 bins
Training	15 s delay between chains	3	Yoked responses
Day Six (Low)			
Retention	None	3	3 bins
Distracter	None	6	20 bins
Training	15 s delay between chains	1	Yoked responses

Conditions Repeat Twice

Appendix C

Arrangement of Chains during Components of Each Experiment

Position of Correct Responses during Experiments

Link 1	Link 2	Link 3
	Experiments I, II, and VI	
	Retention and Training Components	
1	3	2
2	1	3
3	2	1
	Experiments III, IV, and V	
	Retention and Training Components	
1	3	2
2	1	3
3	2	1
	Distracter Component	
1	2	1
2	3	2
3	1	3

Appendix D

Institutional Animal Care and Use Committee Approval Letter

A copy of the Animal Care and Use Committee Approval Letter is on file at The Graduate College.

BIBLIOGRAPHY

Berquam, E. (1981). *The relation between frequency of response and retention, on a paired associates task.* Unpublished doctoral dissertation, University of Florida, Gainesville.

Binder, C. (1996). Behavioral fluency: Evolution of a new paradigm. *Behavior Analyst*, *19*(2), 163-197.

Brown, P. L., & Jenkins, H. M. (1968). Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior, 11*(1), 1-8.

Bruner, C. A., Avila, S. R., Acuña, L., & Gallardo, L. M. (1998). Effects of reinforcement rate and delay on the acquisition of lever pressing by rats. *Journal of the Experimental Analysis of Behavior*, *69*(1), 59-75.

Cable News Network (2000). 2000 presidential election exit poll results. Retrieved January 17, 2007, from http://www.cnn.com/ELECTION/2000/epolls/US/P000.html

Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin, 132*(3), 354-380.

Doughty, S. S., Chase, P. N., & O'Shields, E. M. (2004). Effects of rate building on fluent performance: A review and commentary. *Behavior Analyst, 27*(1), 7-23.

Driskell, J.E., Willis, R.P., & Cooper, C. (1992). Effect of overlearning on retention *Journal of Applied Psychology, 77,* 615-622.

Dube, W.V., & McIlvane, W.J. (2002). Reinforcer rate and stimulus control in discrimination reversal learning. *Psychological Record*, *52*(4), 405-416.

Evans, S.S., & Evans, W.H. (1985). Frequencies that ensure skill competency. *Journal of Precision Teaching, 6*, 25-30.

Evans, S.S., Mercer, C.D., & Evans, W.H. (1983). The relationship of frequency to subsequent skill acquisition. *Journal of Precision Teaching, 4*, 28-34.

Grace, R.C. (1994). A contextual model of concurrent-chains choice. *Journal of the Experimental Analysis of Behavior, 61*(1), 113-129.

Grace, R. C., Schwendiman, J. W., & Nevin, J. A. (1998). Effects of unsignaled delay of reinforcement on preference and resistance to change. *Journal of the Experimental Analysis of Behavior, 69*(3), 247-261.

Haughton, E. C. (1972). Aims: Growing and sharing. In J. B. Jordan & L. S. Robbins (Eds.), *Let's try doing something else kind of thing* (pp. 20-39). Arlington, VA: Council on Exceptional Children.

Johnson, K.R., & Layng, T.V.J. (1992). Breaking the structuralist barrier: Literacy and numeracy with fluency. *American Psychologist, 47*(11), 1475-1490.

Laraway, S., Snycerski, S., Michael, J., & Poling, A. (2003). Motivating operations and terms to describe them: Some further refinements. *Journal of Applied Behavior Analysis, 36*(3), 407-414.

Lieving, G. A., & Lattal, K. A. (2003). Recency, repeatability, and reinforcer retrenchment: An experimental analysis of resurgence. *Journal of the Experimental Analysis of Behavior, 80*(2), 217-233.

Lindsley, O. R. (1996). Is fluency free-operant response-response chaining? *Behavior Analyst, 19*(2), 211-224.

McKnight, S. D., McKean, J. W., & Huitema, B. E. (2000). A double bootstrap method to analyze linear models with autoregressive error terms. *Psychological Methods, 5*(1), 87-101.

Makepeace, M.D. (1998). *The effect of rate vs. number of emissions of an operant behavior on behavior probability.* Unpublished doctoral dissertation, Western Michigan University, Kalamazoo.

Mazur, J.E. (2001). Hyperbolic value addition and general models of animal choice. *Psychological Review, 108* (1), 96-112.

Mechner, F., Hyten, C., Field, D. P., & Madden, G. J. (1997). Using revealed operants to study the structure and properties of human operant behavior. *Psychological Record, 47*(1), 45-68.

Moran, D. J. (2004). The need for evidence-based educational methods. In D.J. Moran & R. W. Malott (Eds.), *Evidence-based educational methods: Advances from the behavioral sciences.* (pp. 3-7). San Diego, CA: Elsevier Academic.

Nevin, J. A. (1992). An integrative model for the study of behavioral momentum. *Journal of the Experimental Analysis of Behavior, 57*(3), 301-316.

Nevin, J.A., & Grosch, J. (1990). Effects of signaled reinforcer magnitude on delayed matching-to-sample performance. *Journal of Experimental Psychology: Animal Behavior Processes, 16*, 298-305.

Nevin, J. A., Milo, J., Odum, A. L., & Shahan, T. A. (2003). Accuracy of discrimination, rate of responding, and resistance to change. *Journal of the Experimental Analysis of Behavior, 79*(3), 307-321.

Orgel, R. (1984). *Improved learning and motivation in university calculus classes. The BehaviorTech learning system: A training tool for modem times.* Lawrence, KS: BehaviorTech, Inc. (Available through Precision Media, Box 3222, Kansas City, KS)

Péladeau, N., Forget, J., & Gagné, F. (2003). Effect of paced and unpaced practice on skill application and retention: How much is enough? *American Educational Research Journal, 40*(3), 769-801.

Poling, A., & Byrne, T. (2000). *Introduction to Behavioral Pharmacology*. Reno, NV: Context Press.

Poling, A., Cleary, J., Berens, K., & Thompson, T. (1990). Neuroleptics and learning: Effects of haloperidol, molindone, mesoridazine and thioridazine on the behavior of pigeons under a repeated acquisition procedure. *Journal of Pharmacology and Experimental Therapeutics, 255*(3), 1240-1245.

Poling, A., Methot, L.L., & LeSage, M.G. (1995). *Fundamentals of behavior analytic research.* New York: Plenum Press.

Rohrer, D., Taylor, K., Pashler, H., Wixted, J. T., & Cepeda, N. J. (2005). The effect of overlearning on long-term retention. *Applied Cognitive Psychology, 19*(3), 361-374.

Shahan, T. A., & Podlesnik, C. A. (2005). Rate of conditioned reinforcement affects observing rate but not resistance to change. *Journal of the Experimental Analysis of Behavior, 84*(1), 1-17.

Shirley, M.J., & Pennypacker, H.S. (1994). The effects of performance criteria on learning and retention of spelling words. *Journal of Precision Teaching, 12*, 73-86.

Squires, N., & Fantino, E. (1971). A model for choice in simple concurrent and concurrent-chains schedules. *Journal of the Experimental Analysis of Behavior*, *15*(1), 27-38.

Thompson, D. M. (1973). Repeated acquisition as a behavioral base line for studying drug effects. *Journal of Pharmacology and Experimental Therapeutics, 184*(2), 506-514.

Thompson, D. M., Mastropaolo, J., & Winsauer, P. J. (1986). Repeated acquisition and delayed performance as a baseline to assess drug effects on retention in monkeys. *Pharmacology Biochemistry and Behavior, 25*(1), 201-207.

Walker, V. L. (2005). The role of reinforcement rate on fluency. Unpublished master's thesis, West Virginia University, Morgantown.