ORDER EFFECTS OF VARIABILITY-CONTINGENT AND VARIABILITY-INDEPENDENT

POINT DELIVERY: EFFECTS ON OPERANT VARIABILITY AND

TARGET SEQUENCE ACQUISITION

Coral Em Lee, B.S.

Thesis Prepared for the Degree of

MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

May 2004

APPROVED:

Sigrid Glenn, Major Professor
Jesus Rosales-Ruiz, Committee Member
Manish Vaidya, Committee Member
Richard Smith, Chair of the Department of
    Behavior Analysis
Sandra L. Terrell, Interim Dean of the Robert
    B. Toulouse School of Graduate
    Studies

Lee, Coral Em. <u>Order effects of variability-contingent and variability-independent point delivery: Effects on operant variability and target sequence acquisition</u>. Master of Science (Behavior Analysis), May 2004, 60 pp., 2 tables, 28 illustrations, references, 20 titles.

Previous research has shown that variability is a reinforceable dimension of operant behavior. Additionally, it has been demonstrated that learning is facilitated when variability in responding is high. In this research, variability was observed within an operant composed of any sequence of six left and right key presses. Variability was either a requirement for point delivery (VAR conditions) or points were delivered independent of variability (ANY conditions). Two groups of college undergraduates experienced different orders of conditions. One group began the experiment under VAR conditions, and the variability requirement was later removed. The other group began the experiment under ANY conditions, and the variability requirement was later added. A concurrently reinforced target sequence (i.e., an always-reinforced sequence of left and right key presses) was introduced to both groups after these orders of conditions had been experienced. A variety of outcomes resulted. Subjects learned the target sequence when variability was both high and low with non-target points concurrently available. Other subjects learned the target sequence after all non-target point deliveries had been suspended. One subject failed to acquire the target sequence at all. These results were compared to previous findings and possible explanations for the discrepancies were suggested.

ACKNOWLEDGEMENT

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INTRODUCTION

A generic model of selection has been proposed as a means to understand evolution by selection in any domain (Hull, Langman, and Glenn, 2001). According to this model, evolution requires three elements. First, there must be a cohesive population from which members can be selected via some selection mechanism. For example, in the evolution of species, organisms having inherited characteristics better fitted to their environment are more likely to survive and reproduce those characteristics than organisms having characteristics less well fitted to that environment. For behavior, the selection mechanism is reinforcement. That is, from amongst the members of an operant, some instances with particular dimensions are followed by reinforcers, making those particular dimensions more likely to occur in later responses.

Once selected, there must be a process by which characteristics are replicated. Replication processes in biology have become fairly well understood since Watson and Crick discovered the biochemistry of inheritance. Although behavioral replication is less well understood, behavioral neuro-science can be expected to provide similar insights in the future. However, these two processes would not result in evolution, or the gradual shift in characteristics of a population, if it were not for the third necessary element of the selection process: variation.

In natural selection, variation in inherited properties of organisms of a species results from genetic mutation, crossover, and meiosis. Without variation within the population, differential selection would not be possible and species could not remain adapted to changing environments. The same holds true in the case of behavior. Without variability, operant learning would be nearly impossible because no novel responses would be available when reinforcement contingencies changed. In other words, "variability provides the necessary substrate from which

a response must be selected" (Neuringer, Deiss, & Olson, 2000).

Three primary sources of variability in behavior have been identified (Neuringer et al. 2000). First, there is some endogenous variation within an operant. Also known as operant or baseline level of variability, this type of variability may be the result of the physical impossibility of repeating an identical topography again and again. There is generally a range of dimensions of an operant that fall within the reinforced response class, so many variations of an operant may be reinforced. In this case reinforcement allows variability to occur; however, the cessation of reinforcement is also associated with increased variability in behavior.

Variability also is observed when the presentation of reinforcers following a behavior is discontinued (i.e., in extinction, see Lalli et al., 1994 and Duker & van Lent, 1991 for applied examples) or when the density of reinforcement decreases (i.e., on intermittent schedules) (Eckerman & Lanson, 1969; Tatham et. al 1993). This "extinction induced variability" often accompanies an increase in the rate of responding, as seen during an extinction burst (see Goh et al., 1994) or the higher rates observed during variable-ratio schedules. It is possible that both the increase in variability and the increase in rate are the result of the same history of reinforcement. For example, if a child's yelling usually gets his mothers attention, yelling may increase in rate and show more variability if the mother ceases to response (e.g., if she is on the phone). If the child persists, the mother may eventually respond and unwittingly reinforce both the increased rate and any variations in the yelling behavior. Additionally, however, it is possible that not only are the particular variations of behavior reinforced in this situation, but also the variability itself, resulting in an increased tendency to engage in novel behaviors in the future. In fact, explicit reinforcement of variability has been identified as the third source of variability in behavior.

Many studies have examined the effects of making reinforcement contingent on

variability itself. Pryor et al. (1969) reinforced only those body movements that differed from previously reinforced body movements in dolphins and never-before-seen movements emerged. That is, once the dolphins' entire existing repertoires of flips, jumps, twists, etc., had been reinforced (and thus were no longer eligible for reinforcement), the dolphins began to emit new movements or combinations of movements. Goetz and Baer (1978) made social attention contingent on children's building either novel or repeated block formations and found that the amount of variability was a function of the amount of social attention received. Machado (1989) found that the variation in the pecking patterns of pigeons closely matched an increasing requirement on variability. Ross and Neuringer (2002) found that variability could be manipulated for one dimension of a response while the variability of other dimensions of the response was simultaneously held constant. In each case, it was shown that contingencies placed on variability controlled the amount of variation quite precisely. [Interestingly, the susceptibility of variability itself to be "selected for" is possible not only for behavior. Some species of plants and animals have adapted to constantly changing environments by producing offspring with extremely diverse genetic material (Pollan, 2002). While this "heterozygosity" is present to some degree in all species, it is particularly notable in the apple, which is why all commercial orchards must be populated with "grafted", or cloned, trees.]

Several studies have provided additional evidence that variability among operant occurrences can be increased through direct reinforcement by employing a reversal design. In these studies, the level of variability is observed across conditions while a variability contingency is either present (VAR condition) or absent (ANY condition). Page and Neuringer (1985) exposed pigeons to a VAR/ANY/VAR arrangement and found that the level of variability quickly decreased once a Lag 50 contingency (high variability requirement) was removed. This

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result was replicated when the conditions were reversed twice more. Similar results were reported by Neuringer and Huntley (1991) who exposed rats of various ages and gender to a VAR/ANY/VAR series of conditions. Although there were some differences in the amount of variability among responses emitted by the various groups, all groups exhibited less variability on average during the ANY condition in which the amount of reinforcement delivered was held constant but the variability requirement was suspended.

Both of the above experiments began with a variability requirement that was later removed. In other experiments, initial conditions did not include a contingency on variability. Rather, responses were reinforced regardless of variability, and a variability requirement was added in subsequent conditions. Miller and Neuringer (2000) employed this order of conditions (ANY/VAR/ANY) with adolescents with autism as well as typically developing children and adults. All groups demonstrated low levels of variability initially (when no variability contingency was in place) followed by increased levels of variability once a variability requirement was implemented. However, once the variability requirement was removed, members of all three groups continued to response variably. In fact, only one participant returned to baseline level of low variability. The remainder of participants continued to respond highly variably even though the contingency on variability had been discontinued.

Similar results were reported by Stokes and Balsam (2001) and Saldana and Neuringer (1998), both of whom studied human subjects. In both studies, variability persisted in the second ANY condition, in which variability was permitted but not required for reinforcers to be delivered. Stokes and Balsam went so far as to conclude that this is indicative of an "optimal period", during which the level of variable responding was determined regardless of future contingencies. These findings contrast with studies employing the VAR/ANY/VAR order of

conditions. That is, when the VAR/ANY/VAR order of conditions was used, a decrease in variability was observed once the variability contingency was removed. It appears from this literature that the order of conditions may be a variable in determining whether variability decreases when the contingency requiring variable responding is discontinued. However, it should be noted that studies that produced a reversal in variability levels employed non-human subjects, whereas studies that reported a continuation of variability beyond conditions in which it was required employed human participants.

Given the discrepancies noted in the literature, the experiment reported here sought to investigate the effects that order of conditions might have on subsequent performance. To review, all studies employing a VAR/ANY/VAR order of conditions produced a reversal in variability levels, while studies employing an ANY/VAR/ANY showed a continuation of variability during the second ANY condition. The current experiment compared the performance of human subjects using both orders of conditions.

If the results of the previous studies were replicated (i.e., an initial ANY condition produced persistent variability later) this could be useful in applied work. Any benefits resulting from highly variable behavior could be obtained without the logistical difficulty inherent in monitoring the level of variability in an operant. For example, a creative writing teacher might initially ensure a high degree of plot variation in a student's writing through explicit reinforcement of variability, then later cease tracking variation and concentrate instead on other aspects of the writing such as grammar or vocabulary. Glover and Gary (1976) used a similar procedure to alter number of verb forms, length of responses, and statistical infrequency of responses (i.e., "creativity") used by children to describe common objects. If the research findings generalized, the teacher could expect variations in plot to persist as long as reinforcers

continued to be delivered intermittently. Another applied implication of persistent variability may be found in research on the relationship between variability and acquisitions of new responses (i.e., learning).

Researchers have investigated how variability can contribute to, or facilitate, learning. Some research has demonstrated that greater variation among responses of an operant results in faster acquisition of other behavior. For example, Grunow and Neuringer (2002) required different levels of variability for four different groups and concurrently reinforced emission of particular patterns of behavior called target sequences. Easy and difficult target sequences were tested. Although all groups learned easy target sequences, highly variable groups showed faster acquisition. The facilitative effect of variability was more pronounced for the difficult sequence, for which it was found that "the more variability required by the contingencies, the faster the learning of the difficult target" (p. 255).

These results were to be expected given the previous finding reported by Neuringer et. al (2000). In this study, 30 Long-Evans rats were divided into three groups. Responses consisted of five lever presses distributed across two levers (left and right). For all subjects, an always-reinforced target sequence was available. For the control group (CON group), this was the only operative contingency. For the other two groups, reinforcers were concurrently available on a VI 1-min schedule contingent either on any emitted response (ANY group) or on infrequently emitted responses (VAR group). To clarify, reinforcers were available for the VAR group contingent upon responses emitted less than 3% of the time overall. This contingency usually generates extremely diverse patterns of responding. Results were consistent with those reported later by Grunow and Neuringer (2002): only the subjects in the VAR group learned the target sequence. Subjects in the other two groups (ANY and CON) showed no indication of learning,

although ANY subjects continued to respond at rates comparable to those of VAR subjects. CON subjects' rates of responding declined to near zero. The authors concluded that while "concurrent reinforcers help to maintain responding…only variability-contingent reinforcers facilitate learning" (pg. 108).

In an unpublished Master's thesis, Seymour (2002) replicated the previous experiment using pre-school aged children. Despite the difference in the population, results were similar. Subjects assigned to the ANY condition responded at rates that were comparable to VAR subjects, but all VAR subjects learned the target sequence while ANY subjects did not. One important difference, however, was that two CON subjects in Seymour's replication of Neuringer et. al (2000) maintained high levels of variability and eventually learned the target sequence. The other two CON subjects, whose responding became less and less variable over time, did not learn the target sequence. These findings appear to support the notion that a high level of variability within an operant is a necessary pre-requisite to learning, at least when given the experimental arrangement employed by Neuringer and Seymour.

The question remains whether previous findings can be replicated with a typically functioning adult human population. The current experiment introduced a target sequence to subjects during both VAR and ANY conditions to examine whether variability had a facilitative effect on learning. Previous findings suggest that high levels of variability resulted in acquisition of a target sequence whereas low levels of variability did not lead to learning. Therefore, it was expected that subjects would learn the target sequence during the VAR+ TS condition. The current experiment also examined the role of the order of conditions to determine whether experience with a change in contingencies from ANY to VAR would result in subjects responding variably during a second ANY condition. Acquisition of the target sequence was

therefore examined during both high and low levels of variability under ANY conditions.

To summarize, the current experiment sought to investigate three major points. First, what effect do initial conditions have on subsequent performance when examining operant variability? To answer this question, both VAR and ANY conditions were employed as initial conditions. Second, what effect does level of variability have on learning of a target sequence? Previous research suggested that high levels of variability predict acquisition; the current experiment sought to replicate this effect with an adult human population. Finally, the current experiment was designed to investigate a novel arrangement of contingencies. Specifically, if variability persisted in the absence of a variability contingency (as has been shown with humans during the second ANY condition of ANY/VAR/ANY arrangements), would the same facilitative effect of variability on learning be demonstrated in the presence of high variability but the absence of a variability contingency?

EXPERIMENT 1

Method

<u>Subjects</u>

Six college undergraduate students over the age of 18 participated in the study. Three were male and three were female. Subjects were recruited from the University of North Texas by flyers posted at libraries and the university Union. The first six individuals to respond to the flyer and schedule an initial meeting were chosen to participate. All subjects provided informed consent and were assigned alternately to one of the two groups based on the date of the initial meeting. Meetings were scheduled at the subject's earliest convenience.

<u>Settings, Apparatus, and Materials</u>

Subjects were scheduled seven days a week between the hours of 8 a.m. and 10 p.m. according to subject availability. All sessions were conducted in an experimental room in the Department of Behavior Analysis at the University of North Texas. The room contained an empty bookshelf, a chair, a desk, and a computer on which the experimental program was installed. The program was a modified version of the program described by Neuringer et. al (2000) and replicated by Seymour (2002). The modified program allowed the experimenter to manipulate the experimental condition, the schedule of point delivery, the session length, the length and composition of the target sequence, the color and tone associated with various program functions, and response variability requirements. Only the left and right shift keys on the keyboard were operable once the experiment began. Pressing the Enter key resulted in the presentation of two white rectangles on a black background. The rectangle on the left corresponded to the left shift key and the rectangle on the right corresponded to the right shift key. Whenever a shift key was pressed, the corresponding rectangle turned gray and a tone

sounded. A sequence of six key presses constituted one response. All sessions were ten minutes in length, and up to 6 sessions were completed per day.

Dependent and Independent Variables

The primary dependent variable was the variability of an operant having instances composed of any of 64 possible sequences of six key presses.   Another dependent variable was emission of a target sequence (i.e. a particular distribution of responses between the left and right shift keys, for example, LLLRLL). The target sequence differed for each subject but was always chosen from among responses previously emitted least frequently by each subject.

The independent variable was experimental contingencies first experienced by subjects, conditions herein designated as ANY or VAR. During the ANY condition, points were delivered following any response on a variable interval schedule without regard to the amount of variability. During VAR conditions, points were delivered on a variable interval schedule following rare responses only (i.e., those that occurred less than 3% of the time). Another independent variable was the addition of an always-reinforced target sequence to ANY and VAR conditions. The target sequence contingency was also presented during conditions when points were not available for non-target sequences (i.e., TS ONLY conditions).

Experimental Design

The experiment was arranged to investigate the effects of initial variability requirements on subsequent performance. Subjects were divided into two groups. Group A began the experiment without a contingency on variability (ANY condition). That is, any response emitted after the expiration of the VI timer was followed by point delivery. Group B began the experiment with a contingency on variability (VAR condition); only rare sequences (i.e., responses emitted less than 3% of the time) resulted in point delivery following the

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expiration of the VI timer. After meeting the stability criterion, the variability criterion was

discontinued and subjects continued under ANY conditions. For both groups, the schedule of

reinforcement during these initial conditions was denser than in subsequent conditions. A

decrease in the density of reinforcement was implemented during the ANY condition for both

groups. Conditions conducted under the higher density schedule of reinforcement are labeled

"HD", as shown in Table 1. Following this initial difference, both groups experienced the same

order of conditions: ANY condition with the addition of an always-reinforced target sequence

(ANY + TS), VAR condition with the continued concurrent contingency on the target sequence

(VAR + TS), and a TS ONLY condition in which no points were delivered for non-target

sequences.   This arrangement was designed to investigate the range of conditions under which a

target sequence could be acquired given an appropriate history.

| Group A | | ANY HD | ANY | ANY + TS | VAR + TS | TS ONLY |
| Group B | VAR HD | ANY HD | ANY | ANY + TS | VAR + TS | TS ONLY |

Table 1. Order of conditions by group.

Procedure

Upon entering the experimental room, subjects were seated at the computer and given

the following instructions: "You may use the left and right shift keys to earn points. The more

points you earn, the more money you make". No other vocal instructions were given regarding

how the subjects should accomplish this task; however, a text box on the computer screen read

"Press Enter to begin the session". Sessions began when subjects pressed Enter and ended after

exactly 10 minutes. During each session, two white rectangles were displayed on screen.

Pressing the right shift key caused a change in the color of the right rectangle from white to gray

accompanied by a 0.15-s, 1300 Hz tone. A press to the left shift key resulted in the same change

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in color to the left rectangle and the sounding of a 0.15-s, 1600 Hz tone.

Six shift key presses constituted a response that could be consequated in one of two ways. If the response met the criterion for point delivery, the text "1 POINT" was presented in yellow on a black background for 1-sec accompanied by a 0.02-sec 3100 Hz tone. The two gray squares then immediately reappeared. If the response was not scheduled to be followed by a point, the two squares disappeared, leaving a black screen. A sequence of tones was presented twice (4100 Hz for 0.03-sec, 3600 Hz for 0.05-sec, 2700 Hz for 0.02-sec) and the screen remained black for 3-sec. Any presses emitted during this period of time delayed the next trial by 1.5-sec. At the end of the inter-trial interval, the two gray rectangles reappeared.

Exactly 10 minutes after the subject pressed Enter to begin the session, the following text was presented on the black screen in yellow type: "Session Over. You have earned X points today! Please get the Attendant. Thanks!". The "X" in the text was replaced by the number of points delivered to the subject during the session. Each point was exchangeable for 1 cent or 3 cents, depending on the schedule of reinforcement in effect during the session (i.e., 1 cent during VI-20 sec and 3 cents during VI-1 min). Upon completion of the last session of the day, subjects were presented with a receipt stating how much they had earned that day as well as the total amount accrued over the course of their participation in the experiment. Subjects were paid by personal check when they had completed all phases of the experiment or when they chose to stop participating.

Stability Criteria

During all conditions, data were assessed for stability beginning with the sixth session. Data were considered stable when two conditions were met across three consecutive sessions: the U-value from a session did not differ from the previous session by more than 0.05, and no

trend was evident in the data across these three sessions (i.e., U-value was not consistently

increasing or decreasing). A minimum of eight sessions was required before the data could meet

the stability criterion (i.e., the data from the first five sessions were not examined for stability,

and data from three sessions were required to assess stability). Once data were determined to be

stable, the subject was moved to the next condition in the experimental design.

ANY Condition

A variable interval (VI) schedule of point delivery was in effect during this condition.

Initially, a VI-20 sec schedule was employed. These sessions are denoted herein as ANY HD

(indicating a high density of reinforcement). A timer ran continuously throughout each session

and was set to expire at intervals that ranged from 10-sec to 30-sec. When an interval expired, a

point was stacked and then delivered immediately following the next response. If the next

interval expired before a response occurred, the next point was also stacked. Thus, more than

one point could be stacked at any given time, although points were delivered individually.

Points delivered on the VI-20 sec schedule were exchangeable for one cent.

Later ANY conditions employed a VI-60 sec schedule. During these conditions, the

variable timer was set to expire at intervals that ranged from 10-sec to 110-sec. The first 6-key

response sequence emitted following the expiration of the VI timer was followed by point

delivery. Procedures were identical to the ANY HD condition with one exception: points

delivered during this condition were exchangeable for 3 cents. However, there was no difference

in the stimuli presented when a point was earned (i.e., there was no visual indication to subjects

that the schedule of point delivery or exchange rate had been altered). In both ANY HD and

ANY conditions, point delivery consisted on the yellow text "1 POINT" displayed on a black

background for 1-sec with the accompanying tone. The chance in the exchange rate for points

allowed for the schedule of point delivery to be altered without affecting the amount of money earned.

<u>VAR Condition.</u>

As in the ANY condition, a variable-interval timer ran continuously throughout all sessions. A point was stacked for delivery following the expiration of the VI timer. However, during this condition, only responses that met the current variability criterion were eligible to be followed by point delivery. At first, the variability criterion allowed for fairly common responses to be followed by points. Gradually, the criterion was made more stringent, with points following only very rare responses. The more stringent the criterion, the more variability required for a point to be delivered.

Upon beginning the condition, the variability criterion was set at .1 for all subjects. That is, only responses having occurred less than or equal to 10% of the time could be followed by point delivery. The variability criterion was subsequently lowered (i.e., made more stringent) in increments of 0.01 until a 0.03 variability criterion was reached (i.e., only responses occurring less than 3% of the time could be followed by point delivery). The criterion was lowered whenever the sequences emitted on 3 out of 10 trials met the current variability criterion; if the subject earned no points following 20 consecutive trials, the criterion was increased (i.e., made less stringent) by 0.01. Throughout all sessions, the variability criterion could fluctuate between .1 and 0.03 depending on subject performance.

Subjects who began the experiment under VAR conditions (Group B) experienced a VI-20 sec schedule of point delivery during this condition. Once the data for these subjects stabilized the variability criterion was lifted. Any six-key response sequence emitted following the VI timer was followed by point delivery regardless of how often that response had occurred.

Subject thus began to experience ANY conditions described above. Also as described above, the schedule of point delivery was altered during the ANY condition from VI-20 sec (HD) to VI-60 sec.

ANY + TS Condition

The contingencies operating during this condition were identical to those of the ANY condition except that a target sequence was added. The target sequence was selected from the least-frequently emitted sequences for each subject and point delivery was scheduled for every emission of target sequence (FR-1). Thus, two schedules of point delivery were operable during this condition. A VI-60 sec schedule was in effect for non-target sequences (i.e., every 60 seconds, on average, a non-target sequences was followed by a point), and a continuous schedule of point delivery was in effect for the target sequence (i.e., the target sequence was followed by point delivery each time it occurred).   Data were considered stable when they met stability criterion so long as the target sequence did not occur more than 5 times out of the final 20 trials in the session. If the target sequence occurred frequently towards the end of the session, the current condition remained in effect even if data were otherwise stable until the target sequence was learned. Learning the target sequence was defined as the occurrence of the target sequence on last 5 trials in a session.

VAR + TS Condition

This condition was identical to ANY + TS condition except that the VAR contingencies were in place concurrently with the continuous schedule of point delivery for the emission of the target sequence. That is, points were delivered on a VI-60 sec schedule for non-target sequences provided that the variability criterion (described in the VAR condition) was met. The target sequence was followed by a point each time it was emitted.

<u>TS ONLY Conditions</u>

During this condition, the only points delivered were those that followed the emission of the target sequence. A VI timer was not in operation during this condition and no non-target sequences were followed by point delivery.

Results

Due to high attrition rates during the experiment, only four subjects yielded enough data to include herein (i.e., reached the TS ONLY phase of the experiment). Of these four subjects, one was assigned to Group A and three were assigned to Group B. For all groups, the number of point deliveries across conditions remained fairly constant, with the exception of the decrease in point deliveries resulting from the change in the schedule of reinforcement. That is, approximately the same number of non-target points were delivered during ANY and VAR conditions.

Variability data are displayed in Figures 1-4. Two dependent measures are presented in these figures: uncertainty value (U-value) and percent of sequences emitted per session (% Sequence). U-value is described by Neuringer as a measure of predicted uncertainty of the next response based on a calculation presented in Neuringer et al. (2002).

$$-\sum_{11}^{63} [RF_i \times \log_2(RF_i) / \log_2 (2^{\wedge \text{trial length}} - 1)$$

Please see Neuringer et al. (2002) for a more detailed description of the variables used in calculation of this statistic. For the purposes of this paper, it will be assumed that the U-value is an accepted means by which behavioral variability may be measured. U-value can range from 1.0, which "…indicate(s) that each of the [63] non-target sequences occurred with approximately equal frequency...", to 0.0, which "…indicate(s) that one or more sequences were highly likely, whereas others tended not to occur…" (Neuringer et al., 2000, pp. 103-104). In other words, higher U-values indicate more random responding while lower U-values indicate predictable or repetitive responding.

The second dependent measure presented in Figures 1-4 is percent of sequences

emitted per session. This percentage was calculated by dividing the number of sequences emitted at least one time within a session by 64. For example, if 32 of the possible 64 sequences were emitted during a session, this would yield a score of 50%. Although this measure does not indicate how frequently each sequence was emitted, it is assumed that greater variability resulted in more sequences per session, while highly repetitive responding resulted in fewer sequences.

Variability results for subject A2 are displayed in Figure 1. Overall, variability remained high throughout all conditions regardless of the experimental contingencies. In fact, variability increased initially despite the fact that variation was not required for points to be delivered. In the first condition (ANY HD), U-value increased from 0.79 to 0.92 while percent of sequences increased from 46.9% to 85.9%. The drop in density of reinforcement during the next condition (ANY) did not alter the pattern of variable responding. U-values fluctuated between .86 and .92 and remained high following the introduction of the target sequence in the subsequent condition (ANY + TS) (between .86 and .92). A similar pattern of high variability was observed in the percent of sequences measure, with 75% - 85% of sequences emitted during ANY sessions and 70% - 84% of sequences emitted during ANY + TS sessions.

Despite this high level of variability, the target sequence was not learned in the ANY + TS condition (see Figure 5 for information on target sequence), and so a variability contingency was introduced. This did not produce an appreciable change in the level of variability; previous responding was so highly variable that the variability contingencies in the VAR + TS condition were easily met. U-values observed during the VAR + TS condition ranged from .88 to .94 and percent of sequences ranged from 72% to 89%. Again, however, the target sequence was not learned. Therefore, the TS ONLY condition was introduced, and again, variability persisted. U-values ranged from .91 - .70, and percent of sequences ranged from 35%

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to 82%. The sharp decrease in both U-value and percent of sequences observed during the last session in this condition (U-value of .70 and 35% of sequences) indicates the eventual acquisition of the target sequence.

Figures 5-8 display the number of times the target sequence was emitted during each session. Target sequence data for subject A2 are displayed in Figure 5. The target sequence for this subject throughout these conditions was LLLLRL. This sequence was emitted only 3 times during the ANY + TS condition (once in the second session and twice in the third). The target sequence was never emitted during the last 7 sessions of this condition, although the percent of sequences during these sessions was high. The target sequence was emitted 8 times during the VAR + TS condition, although never more than three times per session. During the TS ONLY condition, the target sequence was emitted a total of 6 times in the first 6 sessions, and was emitted 158 times during the 7th session (this session is displayed in greater detail in Figure 17, which shows the index number of the sequence emitted on each trial of the session). The target sequence (indicated in Figure 17 by open diamonds) was emitted on trial 26, then again on trial 29, and finally on trial 31, after which it was emitted almost exclusively (twice a very similar sequence- LLLRLL- was emitted instead).

Variability data for subjects B2, C1, and C2 are presented in Figure 2, Figure 3, and Figure 4, respectively. Each of these subjects was assigned to Group B, and hence began the experiment under VAR conditions. As with subject A2, the schedule of reinforcement for the first condition was VI-20 sec. All three subjects began the condition with high variability, as shown by U-values in the first session of .87, .85, and .84 and percent of sequences of 62%, 64%, and 65%, in order by subject B2, C1, and C2. Subjects B2 and C1 continued to emit high and stable variable responding throughout the condition, with all U-values above .8 and percent

of sequences above 56% for subject B2 and above 65% for subject C1. Subject C2, however,

produced a downward trend in variability for the first four sessions, with U-values dropping to

.71 and percent of sequences to 46%. Variability then climbed to initial levels and was

maintained throughout the remainder of the condition, with U-values returning to near .8 and

percent of sequences reaching 59%.

The next condition introduced was ANY HD. Subject B2 remained in this condition

for 16 sessions, whereas subjects C1 and C2 remained in the condition for just 4 sessions due to

an experimental decision to change the condition for all subjects simultaneously regardless of

progress on meeting the stability criteria for that condition. This decision was made in order to

maximize the length of exposure to the VI-60 sec schedule of reinforcement for all subjects.

Despite the length of this condition for B2, variability did not decrease. In fact, on ten of the

sixteen sessions, U-values were higher than the highest U-value in the VAR HD condition (i.e.,

responding was more variable). This increase was perhaps more pronounced in the percent of

sequences measure, with one session a full 20% higher than any session in the VAR HD

condition. Similarly, subject C2 did not show any tendency toward a decrease in variability. U-

values that were higher than those produced at the end of the VAR HD condition, and percent of

sequences reached 67%, the highest value yet produced by C2.

Results for subject C1 differed from those of the other subjects in this group. While

variability was maintained for subjects B2 and C2, results for subject C1 show a downward trend

in level of variability during the ANY HD condition. Although C1 remained in this condition

only briefly, the decrease is evident in the last two data points of the U-value measure, which are

both lower than the previous session U-values (from .86 to .81 to .75). Likewise, the percent of

sequences decreased on each subsequent session in the ANY HD condition, dropping from 65%

to 64% in the first two sessions and then to 54% and a low of 42% in the final session.

The switch to the ANY condition with the VI-60 sec schedule of reinforcement produced an immediate increase in levels of variability for subject C1. U-value rose to .86 and percent of sequences reached 73%, both of which were similar to values observed under the VAR condition. These high values were not maintained, however, and variability again began to decrease within four sessions. U-values stabilized around .75 and percent of sequences around 50%. These values were not radically different from those of the other two subjects in this group, both of whom produced slight decreases in variability during this condition before stabilizing around U-values of .80.

Once levels of variability stabilized in the ANY condition, a target sequence was introduced. For subjects B2 and C2, this produced no significant change in measures of variability. The range in U-values for subject B2 was .83-.89 in the ANY condition and .82-.91 in the ANY + TS condition. Percent of sequences ranged from 62%-76% in the ANY condition and 57%-82% in ANY + TS condition. For subject C2, U-values ranged from .73-.82 in ANY and from .76-.83 in ANY + TS. Percent of sequences ranged from 42%-64% in ANY and 50% - 64% in ANY + TS.

Although each subject emitted the target sequence during this condition, neither subject acquired the target sequence. Figures 6 and 8 show data pertaining to the target sequence for subjects B2 and C2, respectively. The target sequence for B2 was LRLLLR. This sequence occurred a total of 5 times during the ANY + TS condition, and three of those instances occurred during the same session. However, no instances occurred during the next session, indicating that these three instances of the target sequence were not the beginning of acquisition. The target sequence for C2 was LRLLLL, and this sequence was emitted twice during the ANY + TS

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condition, once on each of two sessions.

In contrast to the other two subjects in Group B, variability levels for subject C1 dropped significantly during the ANY + TS condition. This decrease in variability was correlated with an increase in the frequency of the target sequence (see Figure 7 for data on the target sequence). In the first session of the condition, variability was similar to the previous condition in that U-values were near .8 and 62% of sequences were emitted. During the next two sessions, however, U-values decreased sharply to .56 and .40 with percent of sequences dropping to 43% and 7%. As shown in Figure 7, the target sequence (RLRRLL) was emitted 46 times during the second session. A similar sequence, RLRLRL, was emitted 45 times, and a closer look at the session data in Figure 15 shows that the subject alternated between the two sequences. In Figure 15, trials during this session are displayed along the X-axis and sequence index number is indicated along the Y-axis. Closed diamonds indicate which non-target sequence was emitted on each trial. Open diamonds indicate emission of the target sequence. This pattern of responding was discontinued early in the third session of the ANY + TS condition, and the target sequence was emitted almost exclusively thereafter (212 times total).

Because C1 learned the target sequence during ANY + TS, the VAR + TS and TS ONLY conditions were not implemented. The other two subjects, however, did not learn the target sequence in the ANY + TS condition, so the VAR + TS condition was implemented for B2 and C2. As in previous conditions, variability remained high for both subjects throughout this condition. For subject B2, U-values were near .9, fluctuating by no more than plus or minus .02 in consecutive sessions, and percent of sequences ranged between 70% and 80%. Overall, there was slightly greater variability in this condition. For subject C2, U-values in VAR + TS averaged .8 and differed by no more than plus or minus .05 across each consecutive sessions.

The percent of sequences measure ranged from 68% to 54% with a decreasing trend overall. Neither subject learned the target sequence during this condition. Although subject B2 emitted the target sequence once in each of three non-consecutive sessions, then twice in a subsequent session, and finally three times at the end of the condition, the target sequence still accounted for less than 3% of total responses. Subject C2 emitted only three target sequences throughout the entire condition.

Both subjects next entered the TS ONLY condition. Within two sessions, subject B2 learned the target sequence. After emitting the target sequence on the last four trials of the first session, B2 emitted the target sequence almost exclusively in the second session of the condition (i.e., on 209 of 213 trials). Subject C2, in contrast, did not acquire the target sequence during this condition. This subject emitted the target sequence once in each of two sessions. After six sessions with no indication of acquisition, the experimental decision was made to remove the subject from this condition.

Figures 9-12 show the rates at which subjects A1, C1, B2 and C2 (respectively) responded across conditions. Rate was calculated by dividing the number of trials in a session by the cumulative time spent in completing those trials. That is, the rate does not represent the number of responses per minute during a session, but the number of responses per minute that would have been emitted had there not been an inter-trial interval. The measure removes the time during which the subject had no opportunity for a reinforceable response. Rate of responding for Subject A2 increased throughout the experiment, from a low of 10 responses per minute in the first session of the experiment to a high of 42 responses per minute during the first session of the TS Only condition. At six key presses per response, this translates into a rate of 252 key presses per minute. The rate then declined slowly and steadily over the course of the TS

Only condition, reaching 34 responses per minute in the last session of this condition.

Subject C1 responded at a rate of between 25 and 30 responses per minute until the last session of the first condition (VAR), when the rate decreased to 18 responses per minute. A sharp increase to 24 responses per minute in the first session of the ANY HD condition was followed by steady decline in rate. A rate of 4 trials per minute was reached in the final session of the ANY HD condition. The introduction of the ANY condition (i.e., the drop in density of reinforcement) brought the rate of responding back to a range of 20-30 responses per minute, where it stayed for the remainder of the experiment. Subjects B2 and C2 responded at fairly stable rates throughout all conditions. The most notable deviations were a short-lived increase in rate for subject B2 upon introduction of the ANY condition (from around 20 trials per minute to around 30 trials per minute for two sessions) and a low point for subject C2 (at 11 trials per minute during the third session of the ANY HD condition). Otherwise, both subjects generally responded at rates of between 15 and 30 trials per minute for the duration of the experiment.

Figures 14-19 show which sequences were emitted on each trial of selected sessions for subjects A2, B2, C1 and C2. For comparison purposes, Figure 13 shows a hypothetical session with randomly generated sequences. Figure 14 shows the first session of the ANY + TS condition for subject C1. Closed diamonds indicate particular sequences emitted in a session and asterisks indicate those sequences followed by point delivery. The target sequence was not emitted during this session, and 11 non-target sequences were reinforced. Of these, two were repeated immediately (i.e., on the next trial). Figure 15 shows the session just prior to acquisition of the target sequence (i.e., the second session of the ANY + TS) for subject C1. Three non-target sequences were followed by point delivery during this session. Of these, one reinforced sequence (index number 8 on trial 19) was repeated on the very next trial. The target

sequence was emitted for the first time in this session on trial 51, and then again on trial 53. After this occurred, a pattern of alternating between the target sequence and one particular non-target sequence was established and continued for the remainder of the session.

In contrast, the second session of the ANY + TS condition for subject A2 (shown in Figure 16) does not show any indication of acquisition. The target sequence (Index number 2) was emitted once during this session, on trial 111, but was not repeated. Whereas subject C1 occasionally repeated a reinforced sequence within one or two trials, subject A2 generally did not repeat reinforced sequences until much later in the session, if at all. For example, the sequence reinforced on trial 84 was not repeated until trial 114. Figure 17 shows the eventual acquisition of the target sequence by subject A2. The target sequence (Index number 2) occurred on trial 26, then again on trial 29, and finally on trial 31, after which it was repeated almost exclusively.

Figure 18 shows the session prior to acquisition for subject B2. Note that the target sequence (index number 17) did not occur until very late in the session, but was then repeated for the remainder of the session (i.e., the last 4 trials). In contrast, Figure 19 shows a session during in which subject C2 emitted the target sequence (index number 16) rather early in the session (on trial 19 out of 96) but failed to repeat the sequence during the session.

Discussion

The results of Experiment 1 show a variety of individual outcomes, some of which are surprising given previous research on the subject of variability. First, all subjects responded variably during conditions in which variability was not a requirement for point delivery. Previous research has shown that, in the absence of a variability contingency, variability declines. Subject A2 engaged in variable responding from the outset of the experiment even though a variability contingency had not yet been experienced. Subjects B2, C1, and C2 were exposed to a variability contingency at the beginning of the experiment, but continued to engage in variable responding despite the fact that the variability contingency had been discontinued.

Second, only one subject acquired the target sequence while non-target points were available concurrently. Previous research has shown acquisition of target responses occurred when a concurrent variability contingency was in place (Neuringer, 2000 and Seymour, 2002) as well as when variability was high and points were available without a variability contingency (Seymour, 2002). This subject (C1) learned the target sequence during the ANY+ TS condition, thereby differing from all the results of previously reported research. Two other subjects failed to acquire the target sequence during the ANY + TS condition, which was predicted by previous research, but also failed to acquire the target sequence during the VAR + TS condition, unlike subjects in previous research. It was necessary to remove the reinforcement of non-target sequences before these two subjects acquired The persistent variability displayed by all subjects prevents a meaningful comparison between groups with different initial conditions. Other studies that began with an ANY condition produced low levels of variability initially, which allowed comparisons to be made with subsequent ANY conditions that were implemented following exposure to VAR conditions. Subject A2 produced variable responding during the

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first ANY condition, rendering a VAR condition unnecessary and comparisons to subsequent

ANY conditions meaningless. Similarly, results from previous research that began with VAR

conditions and transitioned to ANY conditions showed a significant drop in variability once the

variability contingency was discontinued. This was not the case in the current study, and so a

comparison cannot be made between target sequence acquisition under ANY + TS and VAR +

TS conditions, at least not with variability as the relevant distinction.

What might account for these substantial differences between the current research and

other findings? An explanation might be found in the population under investigation. Previous

research has employed either non-human subjects (e.g., Neuringer 2000) or child participants

(e.g., Seymour 2002). The current study employed typically functioning adult humans, and it is

possible that the verbal repertoires of these subjects impacted the outcome. Subject C2, for

example, who failed to acquire the target sequence under the TS ONLY condition, later reported

that he was aware that he could earn points by emitting the target sequence, but that he knew

points were exchangeable for money and he did not want the experiment to show "that he was

only doing it for the money".

Adult human subjects also bring with them into an experiment a lengthy uncontrolled

history, some of which could affect their behavior during the experiment. Subject A2, for

example, was not only insensitive to the lack of variability requirements in the first condition of

the experiment, but also to the schedule of reinforcement. In non-humans, variable interval

schedules typically engender fairly slow, steady rates of responding; Figure 9 shows that this

subject responded at an increasing rate throughout the experiment, eventually reaching a rate of

over 4 key presses per second. While this performance is not surprising in humans, the increase

in rate was more pronounced for this subject, suggesting that some unknown extraneous

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variables, in addition to experimental contingencies, were exerting control over this subject's behavior.

Several other factors might account for the unexpected results. Near the beginning of the experiment, all subjects experienced a change in the schedule of reinforcement from VI-20 sec to VI-1 min. This change was made after examining initial results and finding that variable responding was occurring under conditions where variability was not anticipated. It was hypothesized that the density of the schedule of reinforcement might have resulted in a large number of different sequences being followed by point delivery, and hence an increase in variability by the sheer volume of different sequences being reinforced. To attempt to correct this situation, the schedule of reinforcement was changed to VI-1 min. Variability persisted. In fact, this adjustment to the schedule of reinforcement, coming part way through the experiment, may have contributed to continuation of variable responding. To illustrate, Figure 3 shows that variability had begun to decline during the ANY HD condition for subject C1, but the drop in the density of reinforcement immediately increased the level of variability produced by the subject. Because it is unknown what was maintaining the variability prior to the change from ANY HD to ANY, it is impossible to tease out how much of the subsequent variability resulted from the drop in density of reinforcement.

Two other variables might have increased the amount of variability produced by the subjects. Each press of a shift key caused the rectangle on the screen to turn dark and a tone to be emitted. Each key corresponded to a different tone. When a subject entered a sequence, a distinct auditory pattern was produced. Subjects were observed to alter the latencies between presses, resulting in miniature "tunes" being played on the computer. It is possible that the sound of the tones was enough to reinforce variability in the absence of a variability contingency.

That is, the auditory feedback received from pressing different sequences might have automatically reinforced variable responding.

Another variable that may have increased the probability that subjects would produce variability was the lack of specific instructions as to how they should accomplish shift key presses. When Seymour replicated Neuringer (2000), he instructed the subjects to press the keys using only one hand. To change keys, the subject had to move their hand to the other side of the keyboard. Subjects in the current experiment were only instructed to press the keys; how many hands should be used to complete this task was not specified. Subjects were observed to place one finger from each hand on each of the shift keys, and in this way alternate between shift keys. In this case, variable responding required little or no extra effort as compared to pressing the same key again and again. This may have contributed to the persistence of variable responding throughout the experiment.

At the end of Experiment 1, the question remained as to whether it was possible to generate repetitive responding in typically functioning adult human subjects so that the effect of variability contingencies could be examined. Hypothesized reasons for the persistence of variability were the change in schedule of reinforcement experienced by subjects of Experiment 1, the distinct tones produced by each of the two shift keys, and the fact that subjects were permitted to use both hands to enter sequences. Experiment 2 was designed to control for these variables by implementing a VI-1 min schedule from the outset of the experiment, using the same tone for each of the shift keys, and adding the instruction that subjects press the shift keys using only one finger.

EXPERIMENT 2

Method

Four college undergraduates over the age of 18 participated. Three were female and one was male. Subjects were recruited from an undergraduate introductory behavior analysis course and were randomly chosen from a pool of students who expressed interest in participating. Setting and apparatus were identical to those employed in Experiment 1; however, the maximum number of sessions allowed to be completed per day was increased to 12.

Procedures

All procedures in Experiment 2 were identical to those in Experiment 1 with three exceptions. Upon being seated in front of the experimental computer, subjects were giving the following instructions: "You may use the left and right shift keys to earn points. The more points you earn, the more money you make. Please press the shift keys using only one finger." The experimenter then demonstrated using one finger to alternate between the two shift keys by pressing left, right, left with the index finger of the right hand. A second change in procedures of Experiment 2 involved the tones that corresponded to the two shift keys. Rather than having a different tone for each shift key, both keys were programmed to result in a .05-s, 600 Hz tone. Finally, all subjects in Experiment 2 began the experiment on a VI-60 sec schedule regardless of the condition that the subject experienced first. There were no other procedural variations between Experiments 1 and 2.

Results

Of the four subjects in Experiment 2, two subjects (designated A3 and B3) ceased to participate after 16 and 8 sessions, respectively. Their data are not included in the results as they were incomplete and inconclusive. Data from the two remaining subjects, A4 and C3, are presented here. Subject C3 experienced the same 5 conditions as Group B subjects in the previous experiment (VAR, ANY, ANY + TS, VAR + TS, TS ONLY). Subject A4, however, remained in the ANY condition (the first condition for Group A) for a total of 23 sessions in an attempt to allow variability to stabilize at low levels. When this did not occur, the decision was made to switch the subject into the ANY + TS condition, foregoing the VAR condition entirely. Data from previous subjects provided information about acquisition of the target sequence when the target sequence was reinforced concurrently with high variability in an ANY condition. This change in contingencies was designed to allow data to be examined from a condition in which a target sequence was reinforced concurrently with a low variability ANY condition.

Variability data from subject A4 are presented in Figure 20. After an initial U-value of .4 and 12% of sequences in the first session of the ANY condition, measures of variability dropped to very low levels during the subsequent 4 sessions (U-values ranged from .18 to .15 and percent of sequences ranged between 4% and 6%). A closer examination of the data from these sessions in Figure 26 reveals that the subject responded primarily by alternating between 2 sequences, each of which consisted of alternating between the two keys (i.e., the sequences the subjects alternated between were LRLRLR and RLRLRL). Following this period of low variability, U-values and percent of sequence measures showed an increasing trend between sessions 5 and 12. U-values rose to a high of .64 and percent of sequences rose to 32%. Variability measures then dipped again to U-value of .33 and 14% of sequences in session 15

before increasing again to an all-time high of .74 (U-value) and 40% of sequences. Finally, a slow, steady decreasing trend was evident between sessions 17 and 23, during which U-values decreased to .34 and percent of sequences dipped to 14%. Interestingly, although the within-session variability in response sequences was lower than all previous subjects, the between-session variation in measures of variability was far greater for this subject than other subjects (i.e., the data did not achieve stability). The next condition experienced by this subject was ANY + TS. Only one session was conducted during this condition due to acquisition of the target sequence. During this session, U-value was .44 and 14% of sequences were emitted.

Figure 22 shows number of target sequences emitted per session for subject A4. The target sequence chosen for this subject was LLRRRL. During the ANY condition, this sequence was emitted a total of 6 times: once in each of three sessions, and 3 times in Session 9. This sequence was chosen because, although it had been emitted on occasion, it was a very rare sequence overall. Having been emitted on just 6 of the 1,746 trials completed up until this point in the experiment, the target sequence accounted for only .0003% of sequences emitted. Considering that a sequence can be reinforced in the VAR condition if it has occurred less than 3% of the time, this sequence definitely qualifies as having a low probability of occurrence. Despite all of this, the target sequence was emitted on the fourth trial of the ANY+ TS condition, and was emitted on 96 subsequent trials. To reiterate, subject A4 acquired a very rare target sequence in one session in the absence of high levels of variability.

Results for subject C3, shown in Figures 21 (variability measures) and 23 (target sequence), are very similar to results from other subjects reported in Experiment 1. High, stable measures of variability were observed during the VAR condition, with U-values averaging .82 and percent of sequences averaging nearly 60%. Only the initial session differed notably from

the other sessions in the condition, with both measures slightly lower at .73 and 42%, respectively. The change to the ANY condition did not alter the pattern of responding, with U-values remaining near .8 for most of the condition (just one point dropped to near .7) and percent of sequences first measuring around 50% and then increasing to mid- to upper- 60's.

The next condition was ANY + TS. Measures of variability decreased steadily throughout this condition, with U-values dropping from .82 to .74 and percent of sequences dropping from 64% to 46%, continuing a trend that appears to have begun at the end of the previous (ANY) condition. The target sequence designated for this subject was LRRRRL, and this sequence had been emitted once during each of the previous two conditions. However, the sequence was not emitted during any session in this condition, and the VAR + TS condition was implemented. During this condition, variability returned to previous high levels, with U-values climbing to .88 and percent of sequences reaching an all-time high of 76% before falling to around 60%.

Whereas the target sequence had not been emitted during the ANY + TS condition, there was a slight but noticeable increase in the frequency at which the target sequence was emitted during the VAR + TS condition. Although never emitted more than twice per session, the target sequence was emitted 7 times during this condition, more than the number emitted in all previous conditions combined. This was not sufficient, however, to consider the target sequence learned, and so the TS ONLY condition was implemented. Due to time constraints, only three sessions were accomplished during this condition, during which levels of variability climbed (U-values of .78, .82, and .86; 57%, 62%, and 71% of sequences) but the target sequence was never emitted.

Figures 24 and 25 show the rates of responding for Subjects A4 and C3, respectively, across sessions. Overall, rates of responding were fairly low as compared to rates emitted by subjects in Experiment 1. The data from subject A4 are very stable, varying by no more than 2 trials per minute with the exception of the first session (which was slightly lower). The data from subject C3 show an increasing trend between sessions 3 and 6 of the ANY condition, with the rate of responding rising from around 13 responses per minute in session 3 to over 20 responses per minute in the last 4 sessions of the condition. Otherwise, however, the data were fairly stable, although relatively higher during the three sessions of the TS ONLY condition.

Individual response sequence data for subject A4 are shown in Figures 26 and 27, respectively, for the session just prior to acquisition and the session during which acquisition occurred. Figure 26 shows that the sequences that occurred most frequently were the sequences that were most frequently reinforced. The target sequence did not occur during this condition, although a similar sequence (i.e., index number 13) occurred three times. Figure 27 shows that the target sequence was emitted on the fourth trial of the first session of the TS Only condition, and repeated for the subsequent 96 trials. Non-target sequences were emitted on the last 7 trials of the session.

Figure 28 shows trial-by-trials data for the most variable session produced by subject C3 (i.e., the 10th session of the VAR + TS condition). Note that the target sequence occurred twice during this session, on trials 11 and 43, as shown in the graph with open diamonds, but the target sequence was not repeated on the next trial either time. However, there was one instance of a reinforced non-target sequence being repeated immediately following point delivery

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Discussion

Subject C3 failed to acquire the target sequence during Experiment 2. However, given the similarity of the data from C3 to subjects in Experiment 1, it is possible that the target sequence would have been acquired eventually had it not been for unfortunate time constraints. Subject C3 engaged in the behavior of repeating a reinforced sequence, at least on one occasion as displayed in Figure 28, during a session in which the target sequence was emitted. Had the target sequence been repeated immediately rather than the non-target sequence, it is likely that acquisition would have occurred. Also, during the TS ONLY condition, the target sequence was never emitted, and it is unknown how quickly, if at all, the sequence would have been acquired had it occurred. If subject A2 is an indicator, the target sequence would have had to occurred several times before acquisition; if B2 is a more appropriate model, the target sequence would have been learned immediately once one point was delivered in this condition.

Whereas the data from subject B3 were similar to data from several subjects in Experiment 1, subject A4 produced a very improbable result by learning a rarely emitted target sequence while demonstrating low variability. Thus Experiment 2 added yet a different outcome to the variety of findings produced in Experiment 1: learning occurred when a target sequence was reinforced in the midst of low levels of variability. The procedural changes made after Experiment 1 may have had the intended effect of facilitating repetitive responding by this subject, but acquisition under these conditions was not anticipated. In fact, previous research shows that repetitive responding tends to inhibit acquisition; this is one of several points on which findings of the current experiment differ from previous research.

GENERAL DISCUSSION

Previous research on variability and learning has produced two main conclusions: variability, like other dimensions of behavior, can be reinforced and extinguished, and variable responding facilitates learning. The results presented here differ from the results of previous research conducted on learning with non-human subjects (Neuringer, 2000), children with autism (Page and Neuringer, 1985), and typically functioning children (Seymour, 2002). For most subjects, "the basic finding…that from a baseline of reinforced variations, sequences were selectively strengthened" (Neuringer, 1993, pp. 85) did not hold true. One element of previous research conducted with college undergraduates was replicated in that variability persisted beyond conditions in which it was required. Although variability remained high, it was often necessary to suspend non-target point deliveries before the target sequence was learned; just once did a subject acquire the target sequence in the midst of reinforced persistent variability. Another subject acquired the target sequence when variability was very low. One subject failed to acquire the target sequence at all. The diversity of outcomes highlights the need for closer examination of the conditions under which past findings can be replicated and the variables that account for the contradictory results found here.

As mentioned before, the extensive verbal repertoires of the subjects almost certainly contributed to the outcome of the current experiments. In an attempt to control for the greater verbal sophistication of college students as compared to children or rats, a six-key sequence was chosen as the response in the current experiment as compared to five keys used by Seymour and by Neuringer. Sixty-four different patterns were thus possible as opposed to 32. This decreased the probability of entering the target sequence from 1/32 (.03) to 1/64 (.015). When Tatham et. al (1993) studied variability in the behavior of adults, a sequence of any eight left and right key

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presses constituted one response, providing precedent for the increase in sequence length. However, Tatham et. al did not employ a target sequence. It is possible that the greater number of available sequences made acquisition of the target response more difficult and prevented subjects from learning the sequence under the expected conditions. Additionally, it should be noted that the target sequence was chosen from amongst sequences emitted least-frequently by the subjects, resulting in sequences being chosen that occurred less frequently than would have been expected if responding was truly random.

Verbal behavior may be an explanatory factor in the persistence of variability beyond conditions under which it was required. Akin to superstitious behavior, subjects reported having generated rules in an attempt to "figure out" how to earn points, assuming that there was a pattern to be discovered. Because specific sequences emitted during the ANY condition were irrelevant to point deliveries, responding in accordance with any rule that a subject devised could be adventitiously reinforced.

During the ANY condition, point delivery could have set up a positive feedback loop in which reinforcers increased the number of different sequences in the response class and thus increased the number of responses available to be followed by point delivery. For example, subject A4 began the ANY condition with very low levels of variability due to the fact that the same two sequences were entered again and again. Variability began to increase, however, in the sixth session when a novel pattern (LLRRLR) was entered and followed by point delivery on the second trial of the session. This single instance of point delivery following a non-repetitive response seemed to be sufficient to briefly increase the amount of variability among responses, as several different patterns quickly followed. The next instance of point delivery, however, happened to follow the "mirror image" of the pattern that had been most recently reinforced, and

thus repetitive responding was reestablished. Because there was no contingency on variability in this condition, the next instance of point delivery could just have easily followed another novel response. Had this occurred, variability might have continued to increase. Instead, the subject began to alternate between the two "new" patterns. Additionally, the sequences that the subject previously relied upon were also entered occasionally. In effect, the number of patterns entered by the subject had doubled. When the number of repeated responses increased, a larger variety of responses were available to be followed by point delivery. This seemed to have led to a net increase in variability across sessions.

Interestingly, although the following of a particular sequence by point delivery may have introduced that sequence into the current response class and thus increased the probability of the response, in another sense it could have decreased the probability of that response. It is generally the case that reinforcers increase the rate of responses having similar features; in fact, this is a defining feature of reinforcement. However, after a sequence was followed by point delivery, responses sometimes became less likely for some period of time. At least, it was rare for a subject to immediately emit a reinforced sequence on the very next trial. This is efficient if a variability contingency is in effect, because the variability contingency essentially puts each individual sequence on a DRL schedule (i.e., differential reinforcement of low rates of responding). Recall that if the sequence is to be available for point delivery it must have been emitted on less than 3% of trials, so repeating a sequence actually decreases the chances that the sequence will be reinforced.

This suppression of repeating responses may have contributed, first, to the insensitivity to changes in condition from VAR to ANY and, second, to the inability of subjects to acquire a target sequence while other sequences were being reinforced concurrently. In the

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first case, if a pattern of repetitive responses was to emerge in an ANY condition, points would have to follow the same sequence on more than one occasion. Because repetition rarely occurred, variability continued to be reinforced adventitiously.   In the second case, absence of repeated reinforced sequences also may have prevented acquisition of the target response. In general, when a target sequence was repeated just once, resulting in points being delivered on two consecutive trials, target sequences were learned. That is, when learning did occur, it occurred very rapidly after repetition was first reinforced. However, subjects generally entered a different response following a reinforced sequence, and did not re-enter the reinforced sequence until later in the session, if at all. Several non-target points were usually delivered before the target sequence was entered again, rendering the target sequence virtually indistinguishable from other sequences. Only after the TS ONLY condition was introduced was the target sequence repeated on the next trial, at which point the sequence was typically acquired immediately.

Perhaps the point deprivation experienced when non-target points were removed increased the reinforcing effect of point delivery to the extent that repetition of a reinforced sequence occurred. This appeared to be the case for subject B2, who, after experiencing 103 trials with no point delivery, immediately repeated the target sequence once it was followed by point delivery. After the target sequence was repeated and reinforced a second time, the target sequence was emitted almost exclusively thereafter. The increased potency of the points as reinforcers in this condition is also suggested in the report of Subject A2, who said that she pressed the same sequence twice "accidentally" prior to acquisition. Stated differently, she might have said that her behavior recurred despite the fact that she did not describe the contingency between the previous response and the point that followed.

The above-mentioned possibilities all pertain to the effects of the experimental procedures, but extraneous variables may also have inhibited the subjects' acquisition of the target sequence. Just as self-constructed verbal "rules" may account for some persistent variability, verbal behavior may have affected acquisition. Recall that subject C2 in Experiment 1 reported that he knew points were exchangeable for money and did not want the results to show he was "only doing it for the money" and so he refrained from repeating the target sequence during the TS Only condition. Results for subject A4 also suggest that verbal behavior may have affected acquisition. Note that the last 7 trials of the session in which acquisition occurred consisted of non-target sequences (see Figure 27). Why would this subject suddenly cease to enter the target sequence? Some anecdotal evidence can be provided by the subject's verbal report upon leaving the experimental room. The subject was apologetic, fearing that the program was "broken" and she had somehow taken advantage of situation by earning too many points. This subject may have ceased to emit the target sequence near the end of the session in an attempt to "cover up" the fact that the target sequence had been learned.

The results from this study seem to indicate that there is a "vary then repeat" pattern that is necessary for a target sequence to be acquired when reinforced concurrently with variable responding. That is, the variability in responding allows for the target sequence to be produced, but unless the subject repeats sequences that are reinforced, the variability itself does not facilitate learning in adults. In these experiments, such repetition was rare; the contingencies all but ensure that a non-target sequence will not be reinforced on two consecutive trials. Given the range of values used in the VI schedules, subjects would have had to respond at a very low rate in order for this to occur. This may be remedied in future research by expanding the range of values used in the VI schedule to include very small intervals (i.e., one second or less).

Regardless, a close inspection of the data produced by subject C1, who acquired the target sequence while non-target points were available concurrently, indeed shows this pattern of "vary then repeat".

During the first session of the ANY + TS condition, there were two instances of a reinforced sequence being repeated on the very next trial (trials 15 and 69 of Figure 14). The target sequence was not emitted during this session; it was emitted, however, during the next session, during which one reinforced non-target sequence was repeated on the next trial. When the target sequence did occur, it was repeated one trial later and a pattern was established. This was a precursor to acquisition, as the non-essential repeated sequence in the pattern dropped out in the next session, leaving only the target sequence.

Other subjects did not quickly repeat reinforced sequences, and also did not acquire the target sequence during conditions in which non-target sequences were reinforced. Again, it was not until the TS ONLY condition that most subjects acquired the target sequence, and it was during this condition that subjects frequently repeated a reinforced sequence. This may have been because deprivation of points was functioning as an establishing operation making points more potent as reinforcers and hence making repetition more likely to occur, or it may have been because the lack of non-target point delivery made the target sequence more easily distinguished from other sequences. Either way, it appears essential that the target sequence be repeated quickly if it to be acquired. Variability, however, played the role of increasing the probability that the target sequence was emitted and thus followed by point delivery.

There is a great deal of evidence that variability can enhance learning. Indeed, it has been suggested that reinforcing variability may provide a means to teach behavior that would otherwise never have been available for reinforcement. That is, "reinforced variation and

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selection may be a *uniquely useful* method to strengthen behaviors that are normally difficult to train" (Neuringer, 1993, pp. 90, italics added). For this reason it is important for future research to carefully examine the conditions under which a concurrently reinforced target behavior can be acquired in the midst of reinforced variation. This could be accomplished by implementing several subsequent ANY + TS or VAR + TS conditions (using new target sequences) following acquisition of the target sequence in the TS ONLY condition. It is possible that the subject would acquire the target sequence under the concurrent schedule in post-TS ONLY conditions. If this occurred, it would be possible to search for differences in responding that allowed learning to take place.

In future research, limitations associated with the current experiments could be eliminated. As noted, time constraints were a factor for several subjects, as the experiments were conducted during a college semester followed by summer vacation. Subject attrition drastically reduced the size of the groups, especially Group A of Experiment 1, which was reduced to just one subject. This limited the amount of information available for comparisons between groups, further weakening an already precarious element of the experimental design. In addition, several conditions were cut short in the interest of time. These conditions might have provided more useful information had they been run for longer periods of time. Most notable were the first ANY condition for subject C1, during which variability declined drastically, and the TS ONLY condition for subject C2, during which the target sequence was not acquired.

Given the data that was produced over the course of these experiments, the question remains as to whether the results are best explained from a molar perspective, with variability being reinforced as a dimension of an operant (i.e., the operant consisting of six key-presses), or from a molecular perspective, with the reinforcement affecting individual instances of particular

six-key sequences. Previous research has viewed variability itself as a dimension of operants based on susceptibility of variability to reinforcement, extinction, and to stimulus control operations. The current research, however, showed that variability was not particularly sensitive to the experimental contingencies. Furthermore, a differential reinforcement of low rates of responding (DRL) schedule operating on each of the 64 individual possible sequences would explain the data just as well as the reinforced-variability hypothesis.

The variability criteria used in the experiment required that sequences be emitted infrequently in order to be eligible for point delivery. This essentially places each individual sequence on a DRL schedule. The theoretical question as to whether the variability contingency or the 64 concurrent DRL schedules account for the results remains open because the experimental contingencies did not distinguish between these possibilities. An operant with instances comprising six key-presses regardless of sequence almost certainly was established, especially given the persistence of high rate and high variability when neither of these values were required for point delivery. The existence of this operant, however, does not preclude the existence of individual

sequences as operants, as was established when the target sequences were acquired. It seems that the molar and molecular perspectives are two sides of the same proverbial coin, a coin that retains the same value regardless of the level of magnification from which it is viewed.

FIGURES

A2
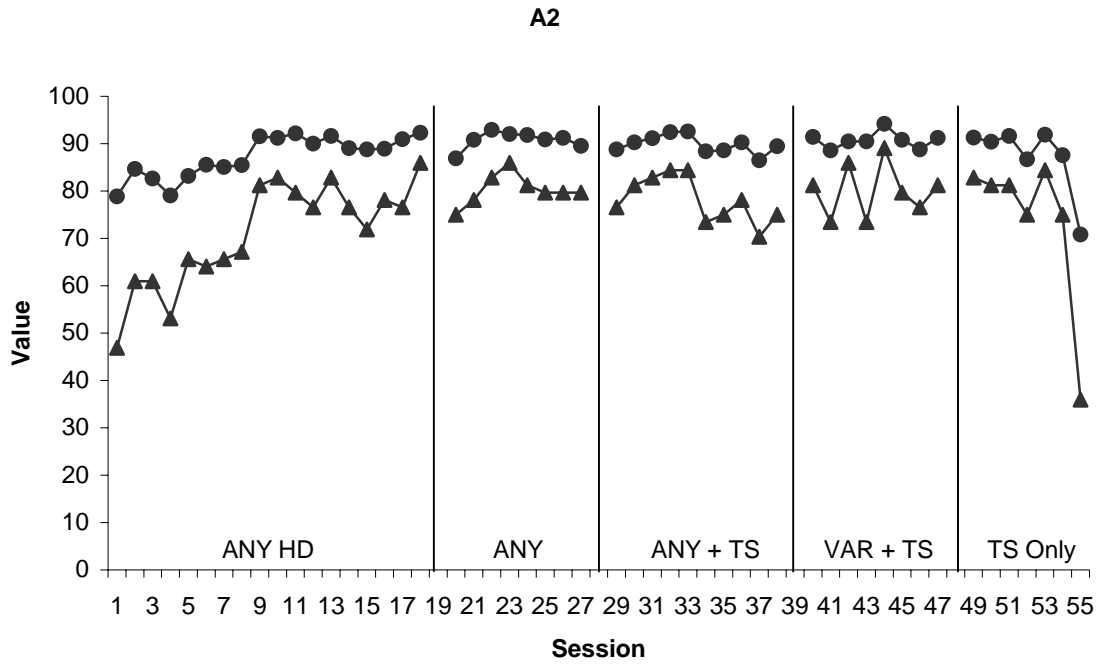
Figure 1. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject A2 across conditions.

B2
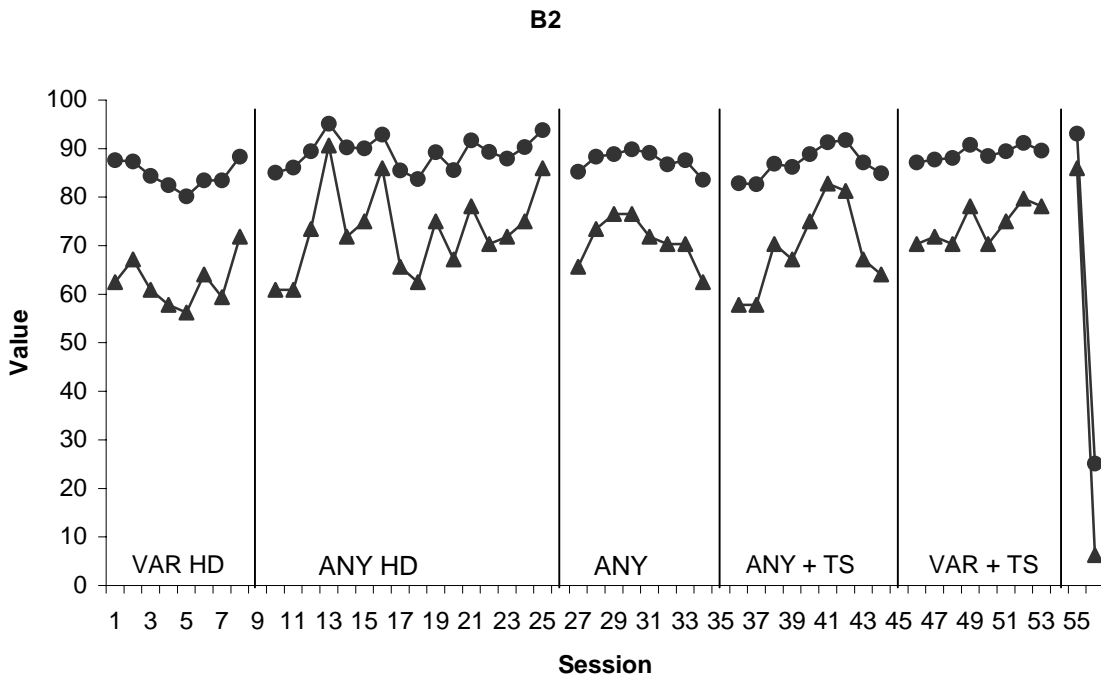
Figure 2. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject B2 across conditions.

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C1
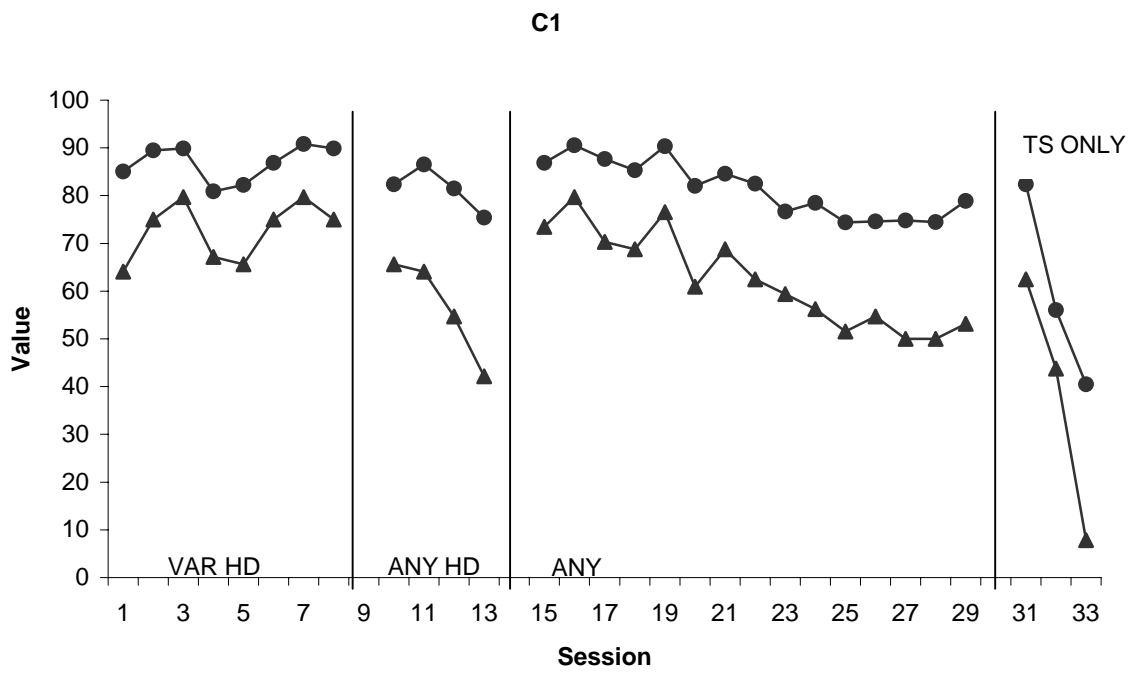
Figure 3. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject C1 across conditions.

C2
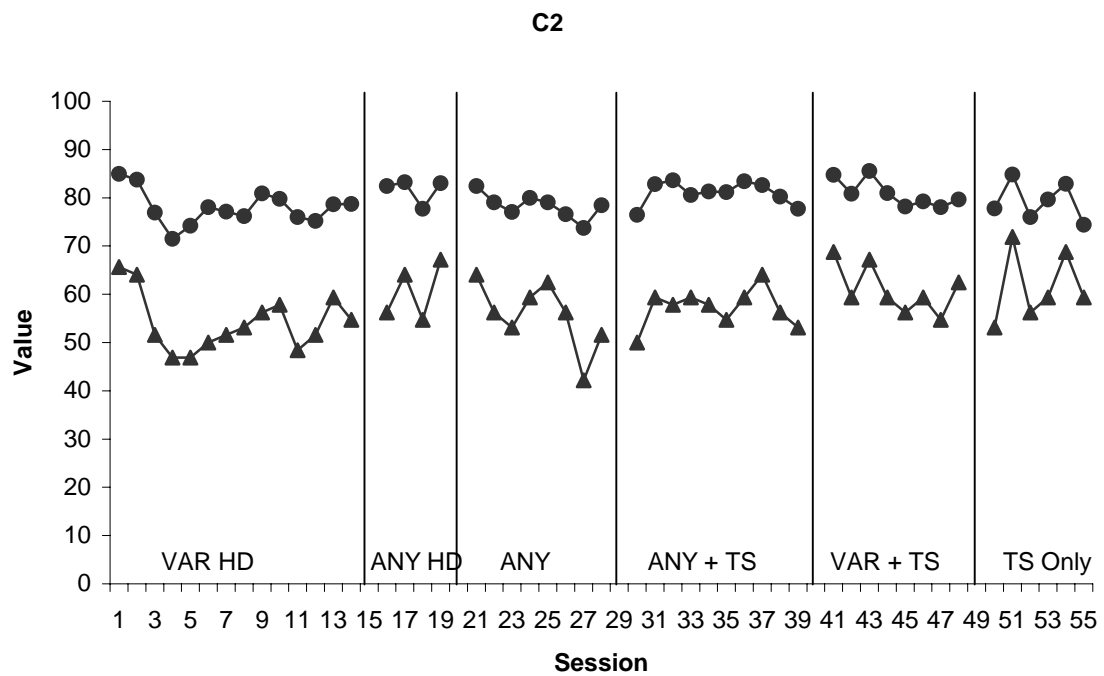
Figure 4. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject C2 across conditions.

A2 Target Sequence LLLLRL
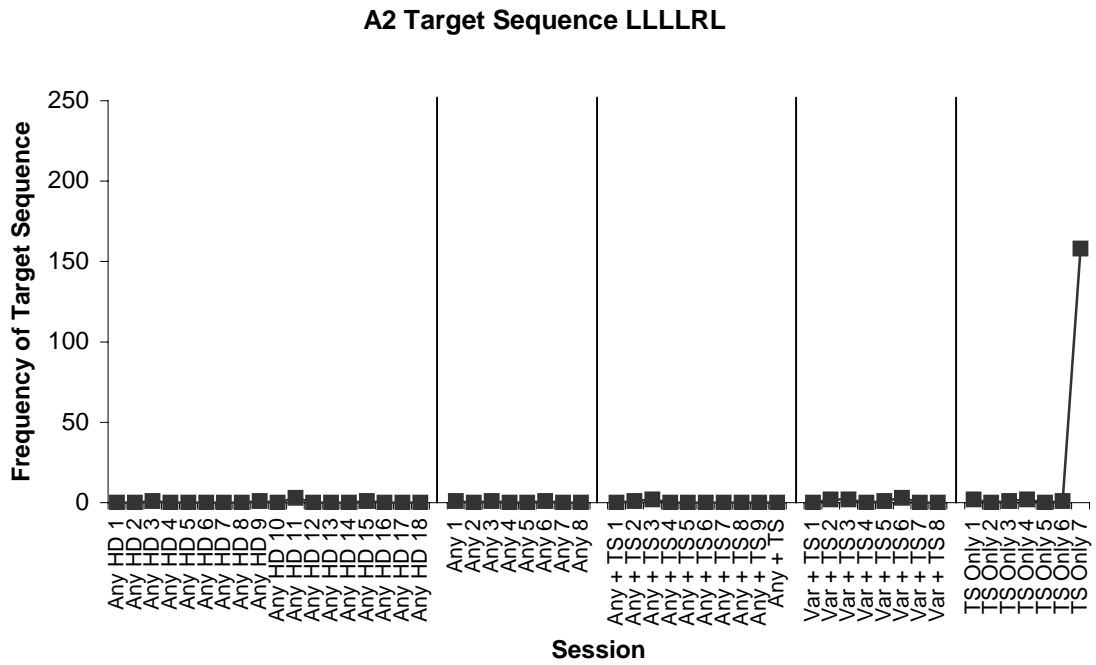
Figure 5. Number of instances of the target sequence per session across conditions for subject A2.

B2 Target Sequence LRLLLR
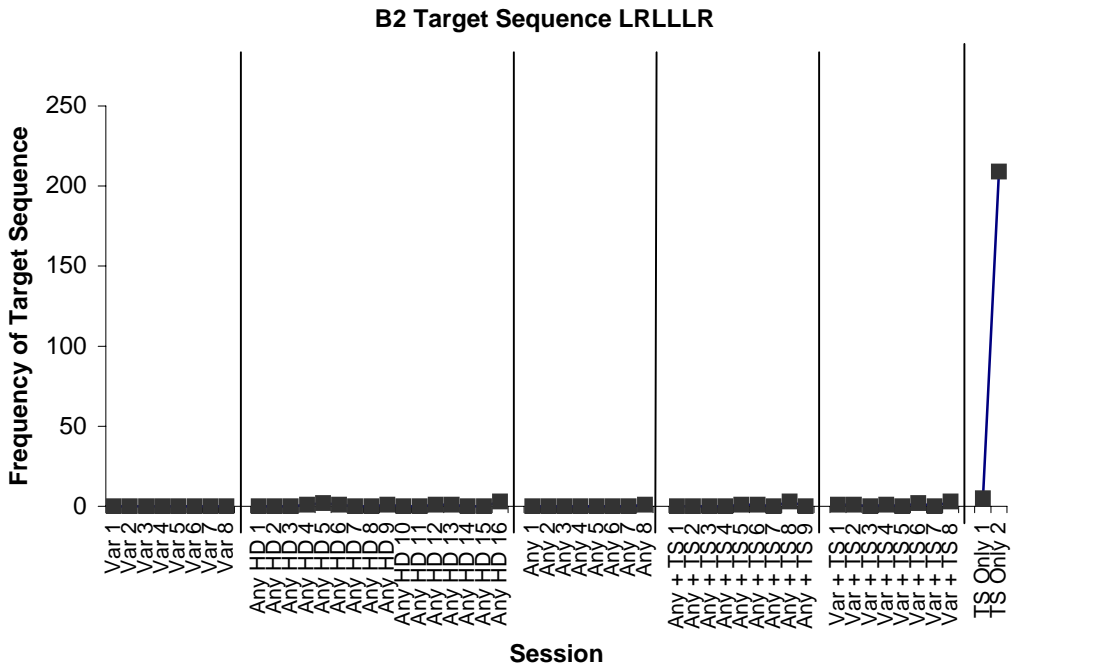
Figure 6. Number of instances of the target sequence per session across conditions for subject B2.

C1 Target Sequence RLRRLL
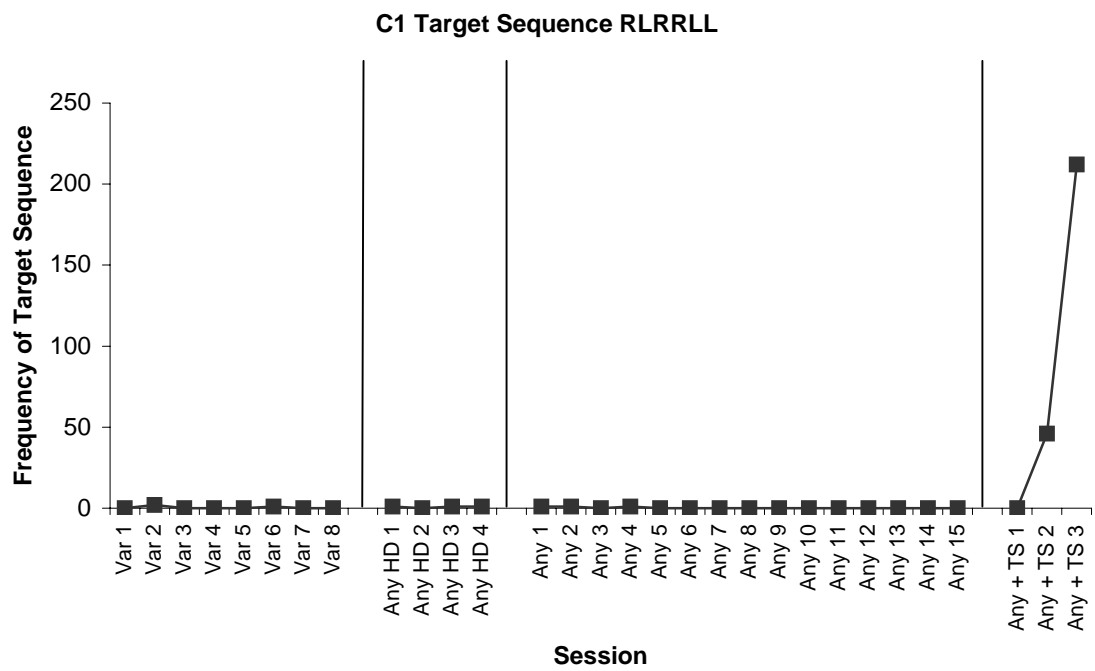
Figure 7. Number of instances of the target sequence per session across conditions for subject C1.

C2 Target Sequence LRLLLL
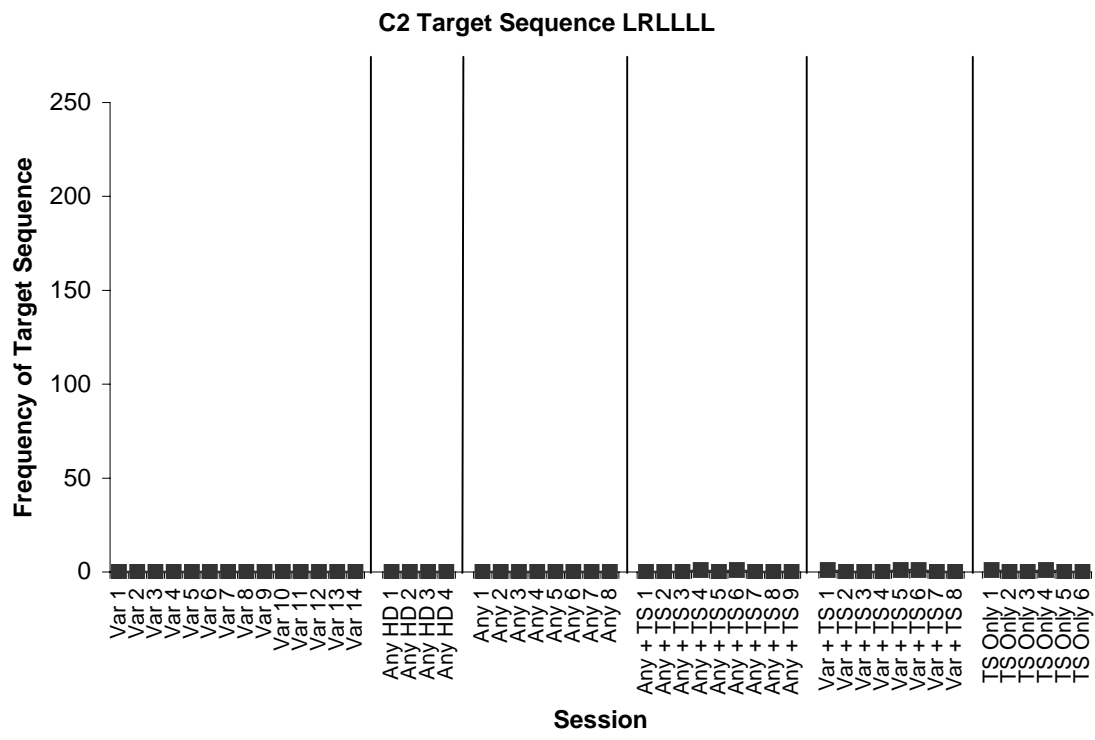
Figure 8. Number of instances of the target sequence per session across conditions for subject C2.

A2
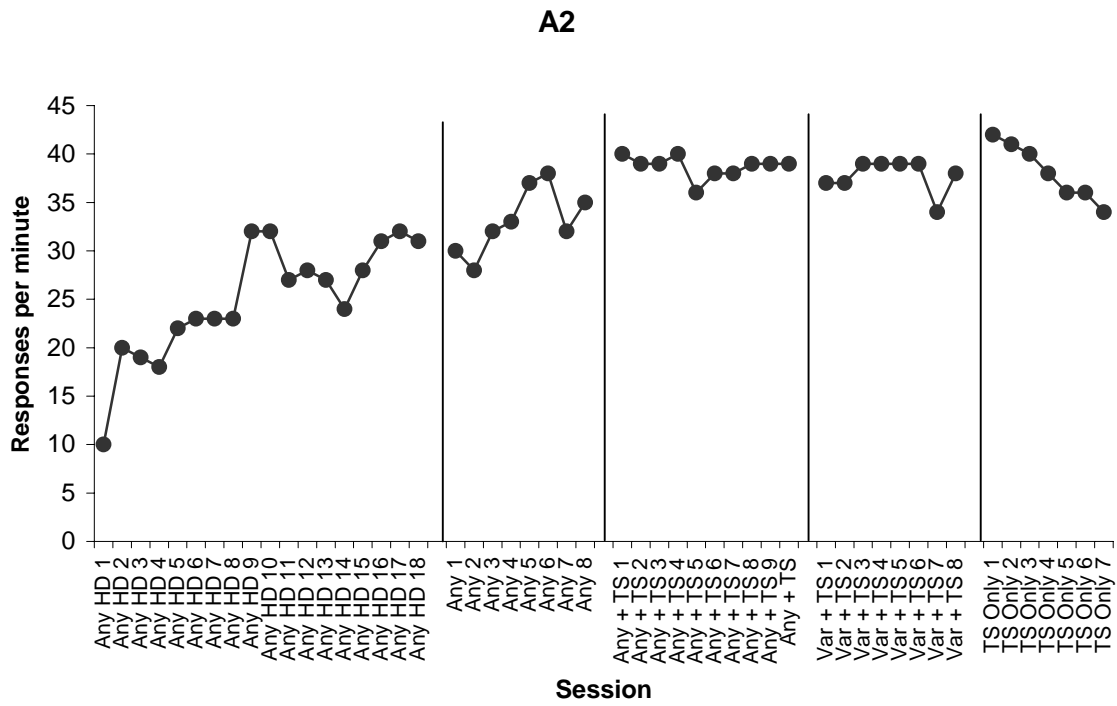
Figure 9. Number of trials per minute emitted by subject A2.

C1
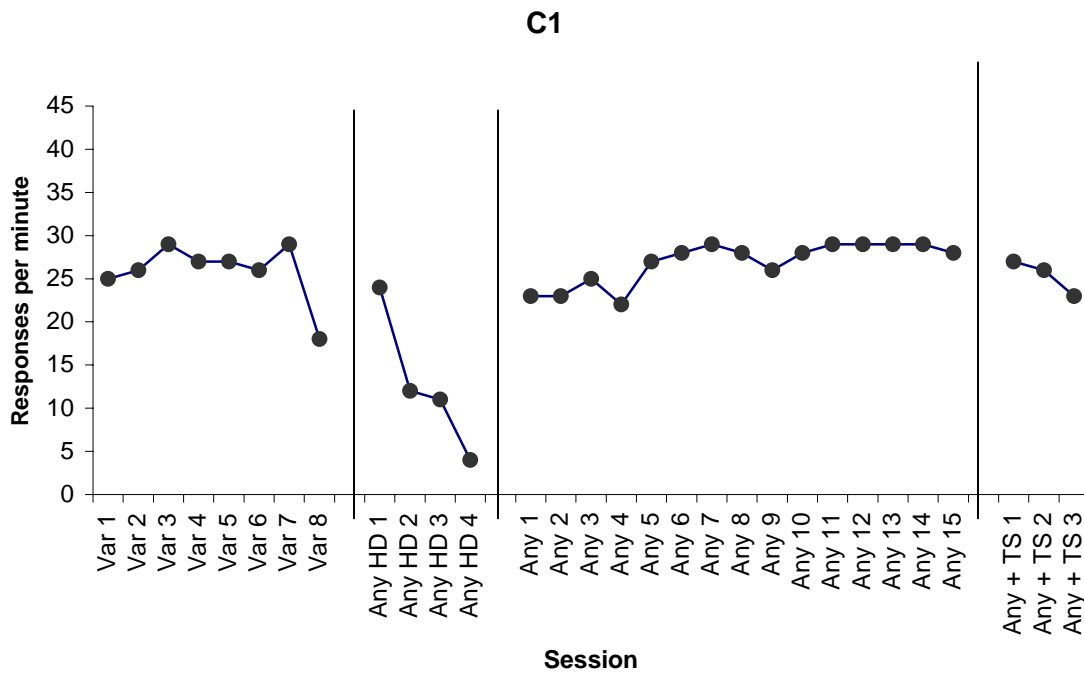
Figure 10. Number of trials per minute emitted by subject C1.

B2
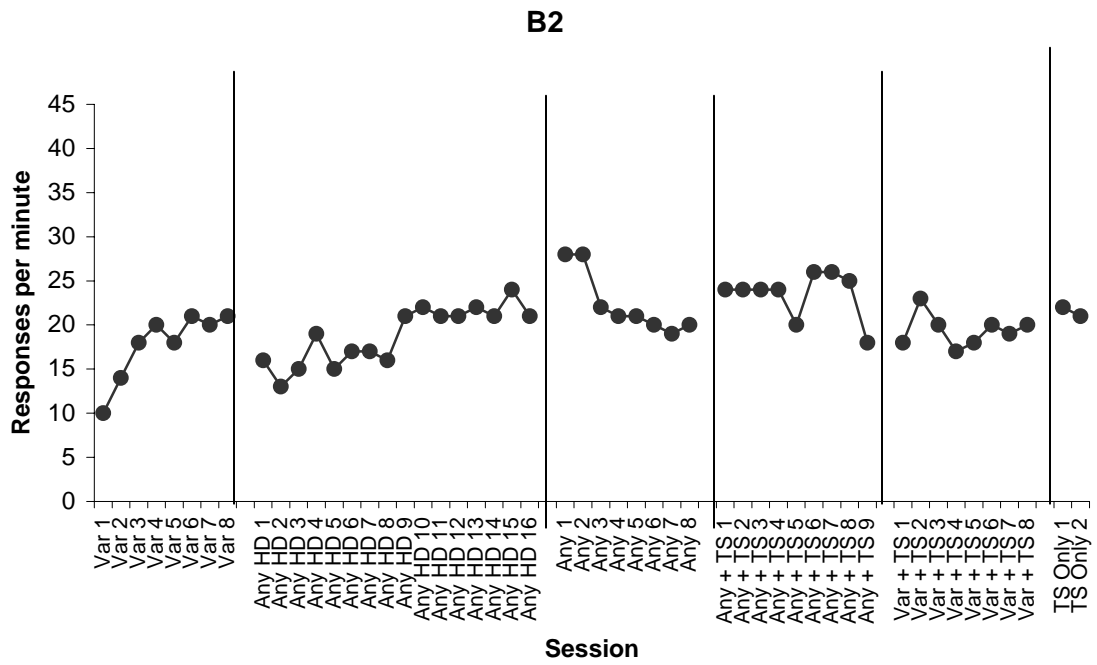
Figure 11. Number of trials per minute emitted by subject B2.

C2
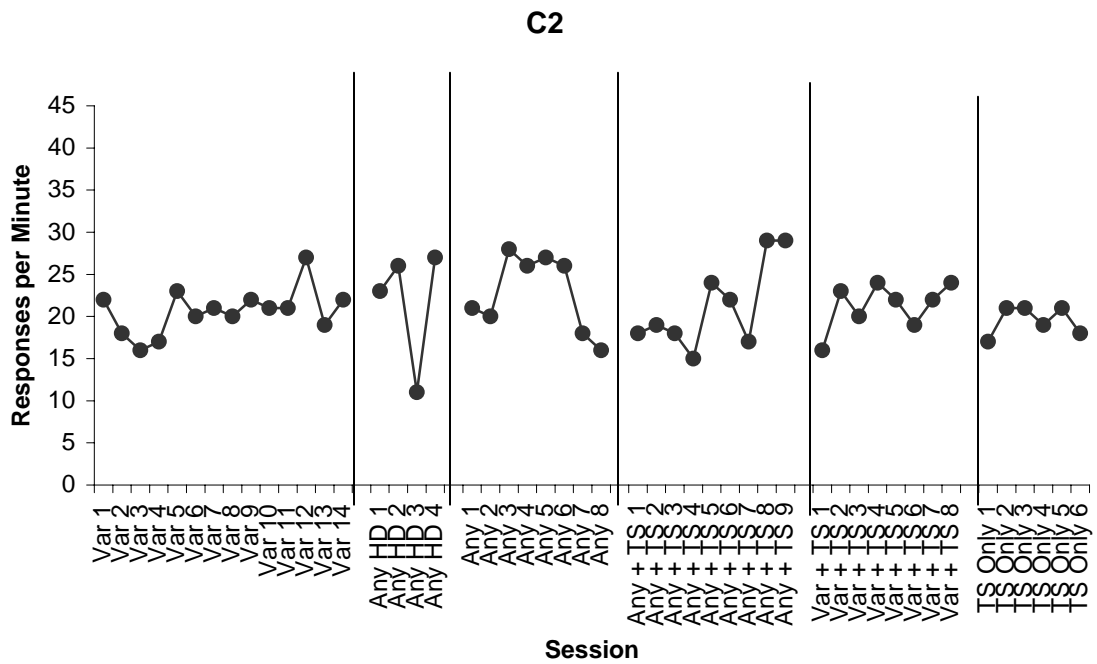
Figure 12. Number of trials per minute emitted by subject C2.

Random Sample
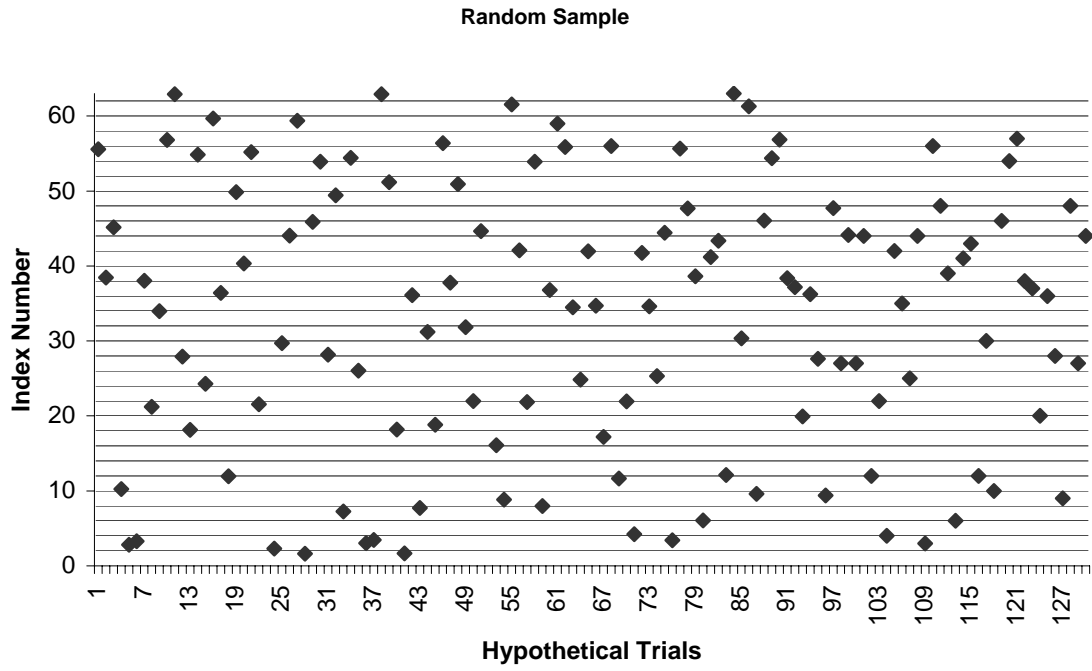
Figure 13. A hypothetical session with random index numbers.

C1: ANY + TS Condition, Session 1
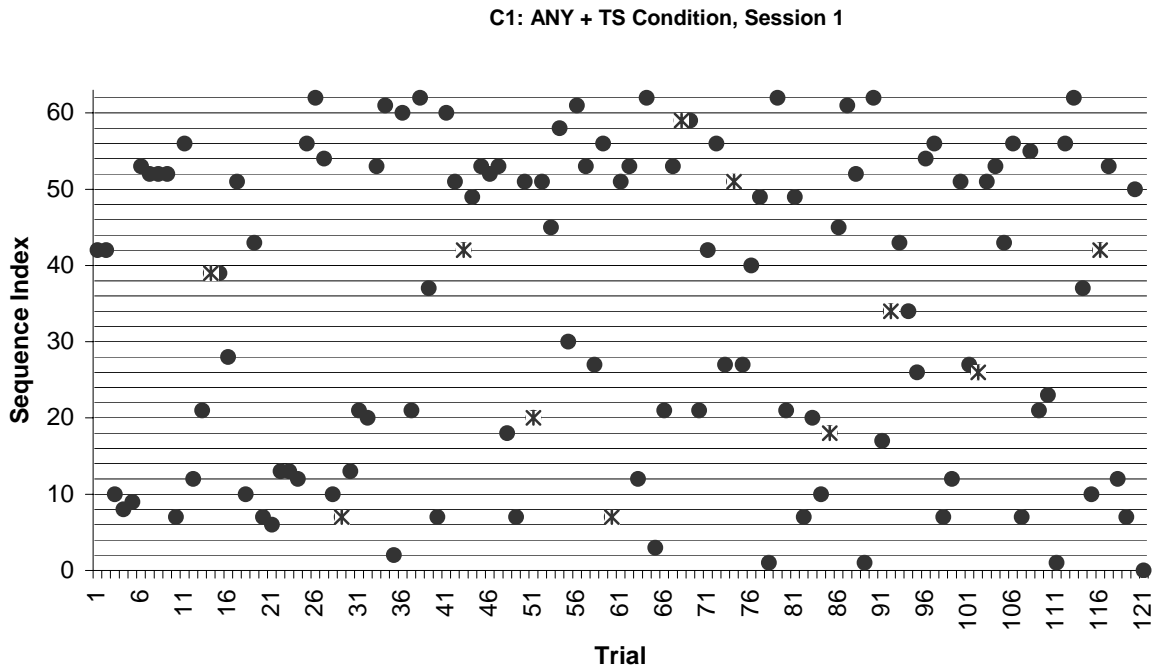
Figure 14. Sequences emitted trial by trial in first session of the ANY + TS condition for subject C1. Asterisks indicate non-target sequences followed by point delivery.

C1: ANY + TS Condition, Session 2
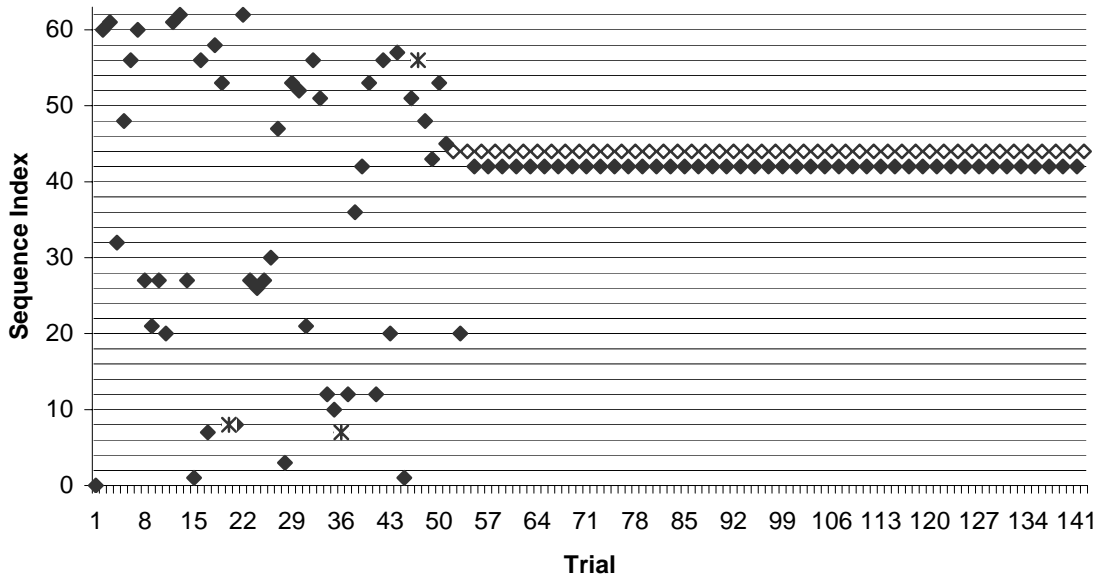
Figure 15. Sequences emitted trial by trial in the session prior to acquisition by subject C1. Asterisks indicate non-target sequences followed by point delivery. Open diamonds indicate the target sequence (index number 44).

A2: ANY + TS Condition, Session 2
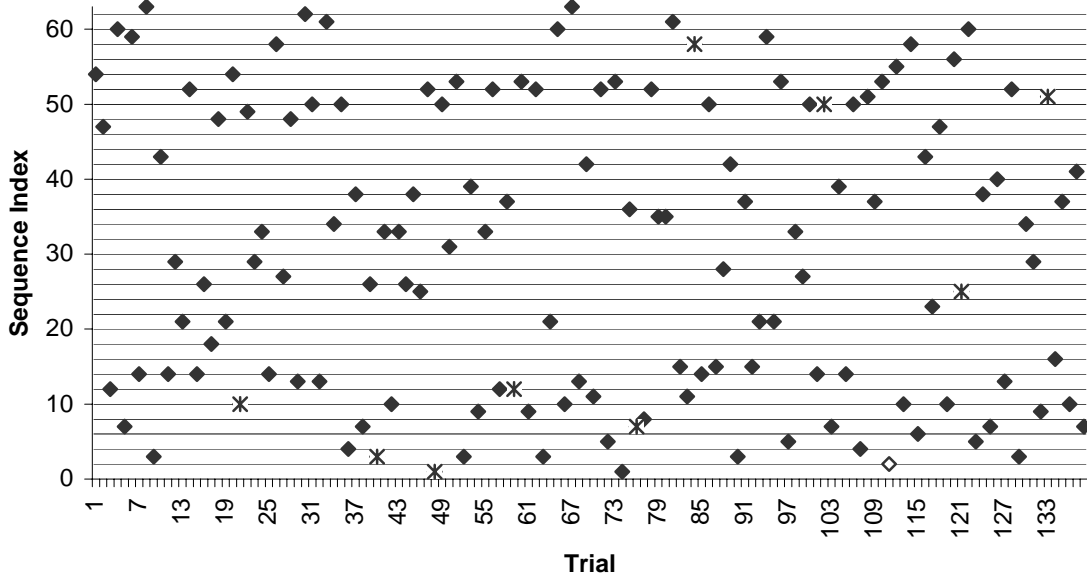
Figure 16. Sequences emitted by subject A2 in the second session of the ANY + TS condition. Asterisks indicate non-target sequences followed by point delivery; the open diamond indicates the target sequence. The target sequence is index number 2.

A2: TS Only Condition, Session 7
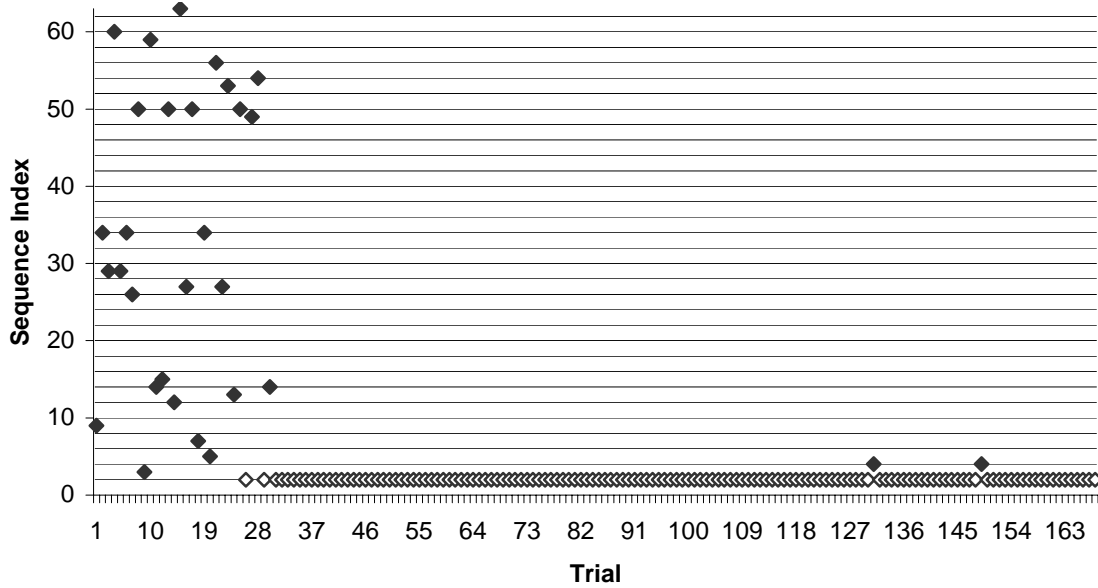
Figure 17. Sequences emitted by subject A2 during the session in which acquisition of the target sequence occurred (i.e., the seventh session of the TS Only condition). The target sequence indicated by the open diamonds (index number 2).
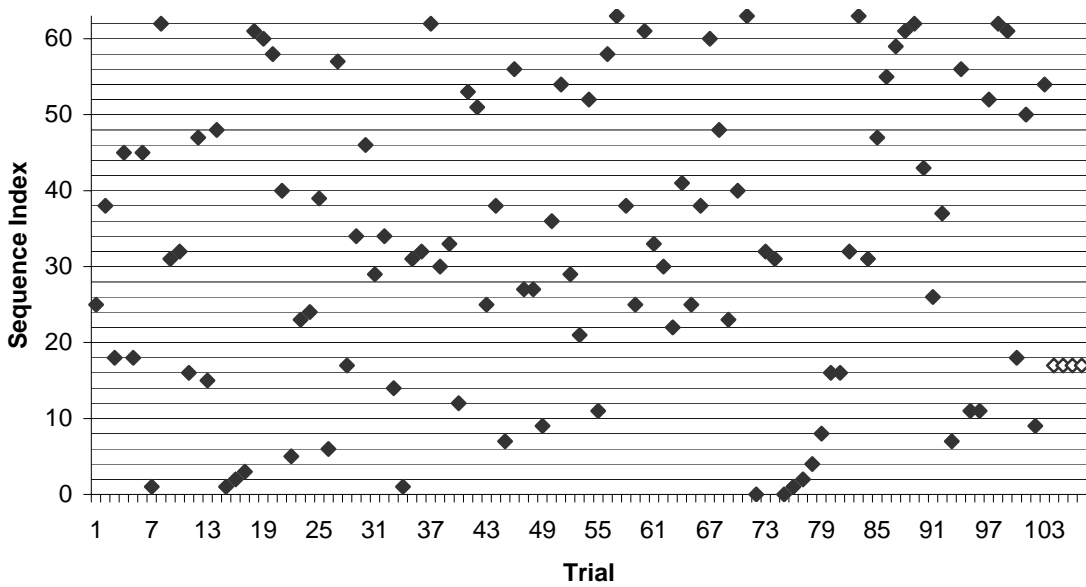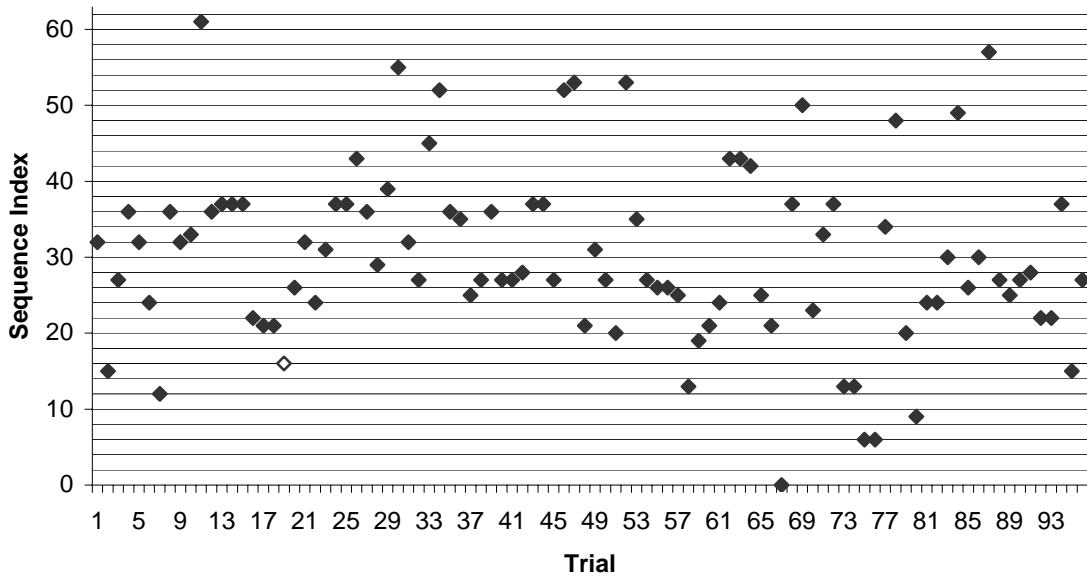
B2: TS Only Condition, Session 1

Figure 18. Sequences emitted by subject B2 during the session prior to acquisition of the target sequence (i.e., the first session of the TS Only condition). The target sequence is indicated by the open diamonds (Index number 17)

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C2: TS Only Condition, Session 4

Figure 19. Sequences emitted by subject C2 session 4 of the TS Only condition. The open diamond indicates the target sequence (index number 16).
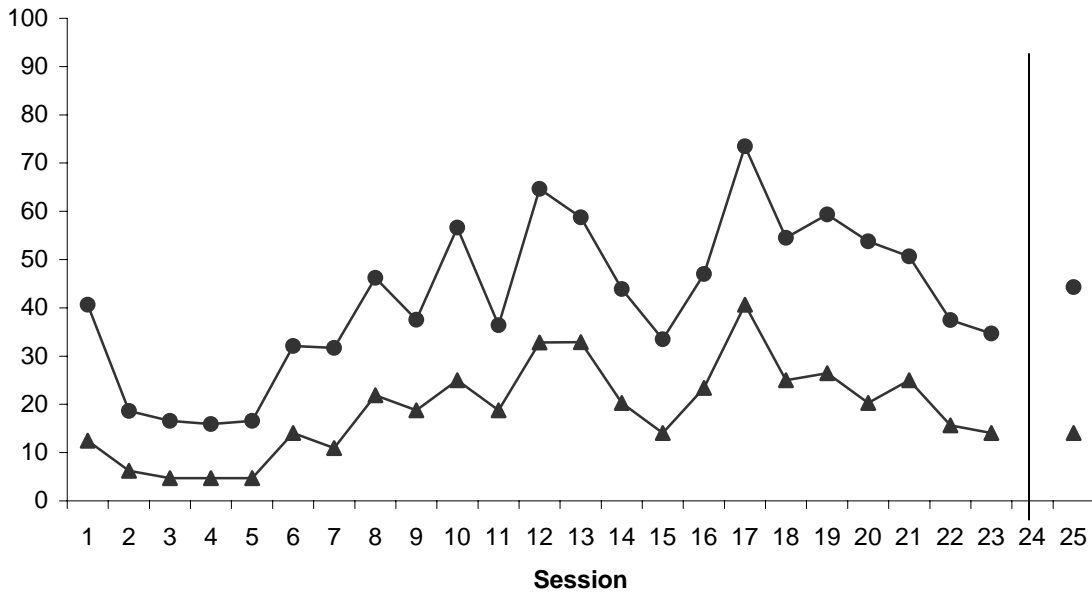
A4

Figure 20. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject A4 across conditions.
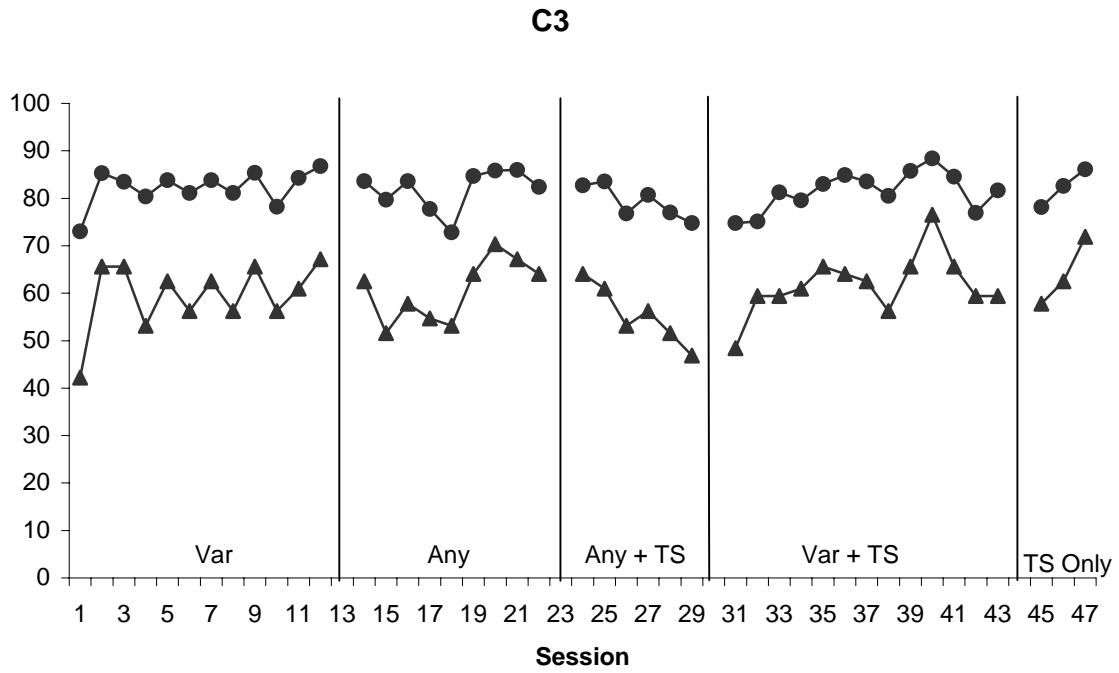
C3

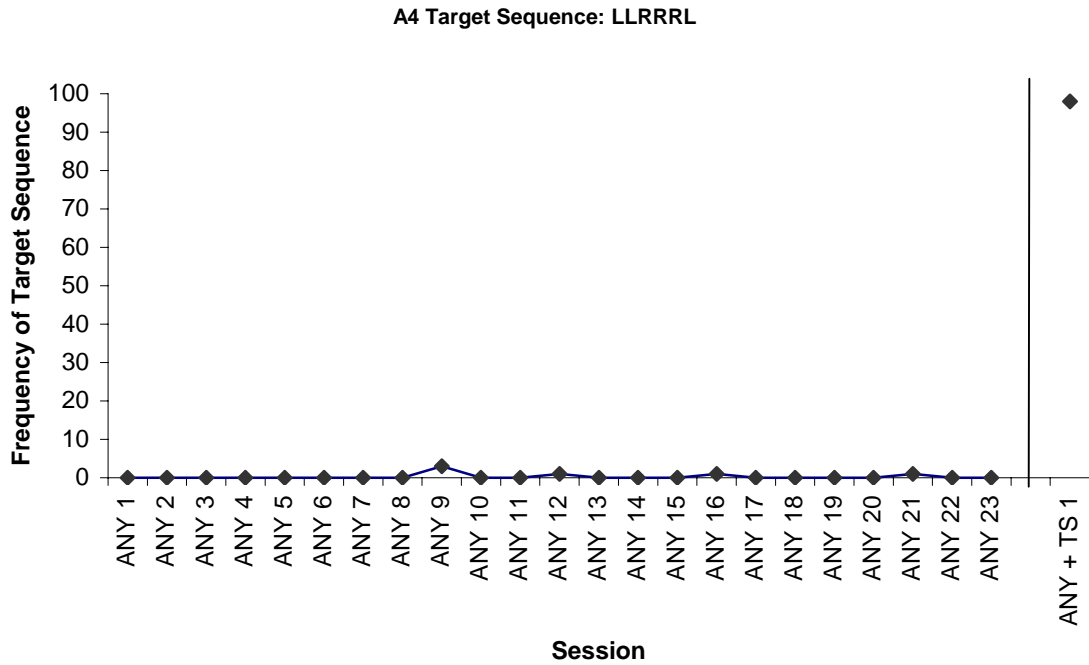Figure 21. U-value * 100 (closed circles) and percent of sequences (closed triangles) for subject C3 across conditions.

A4 Target Sequence: LLRRRL

Figure 22. Number of instances of the target sequence per session across conditions for subject A4.
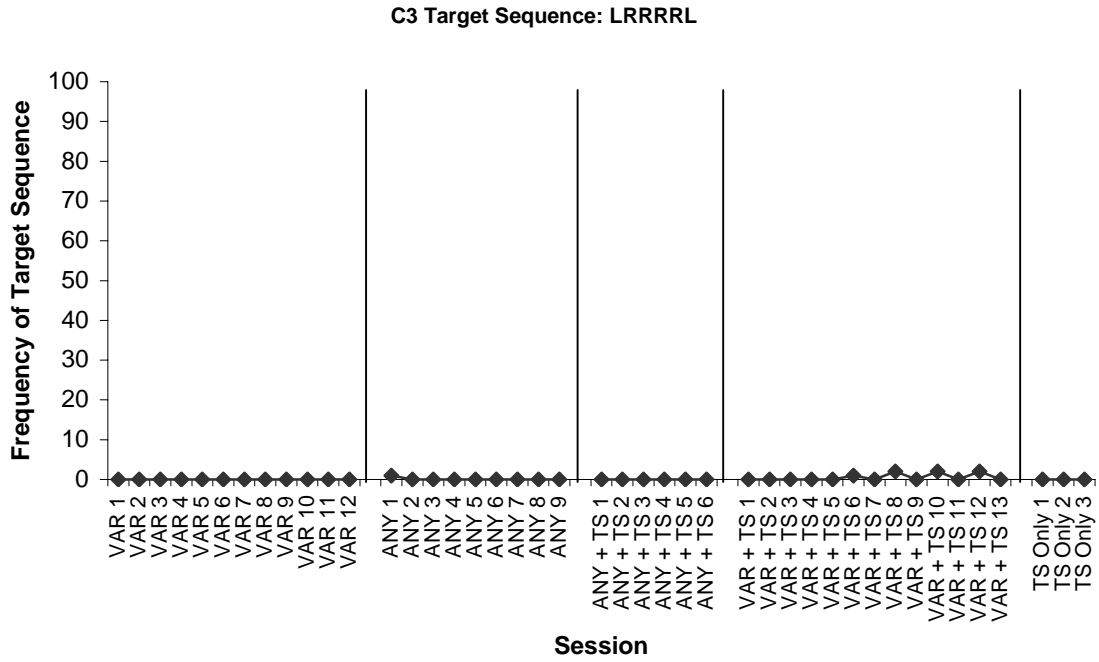
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C3 Target Sequence: LRRRRL

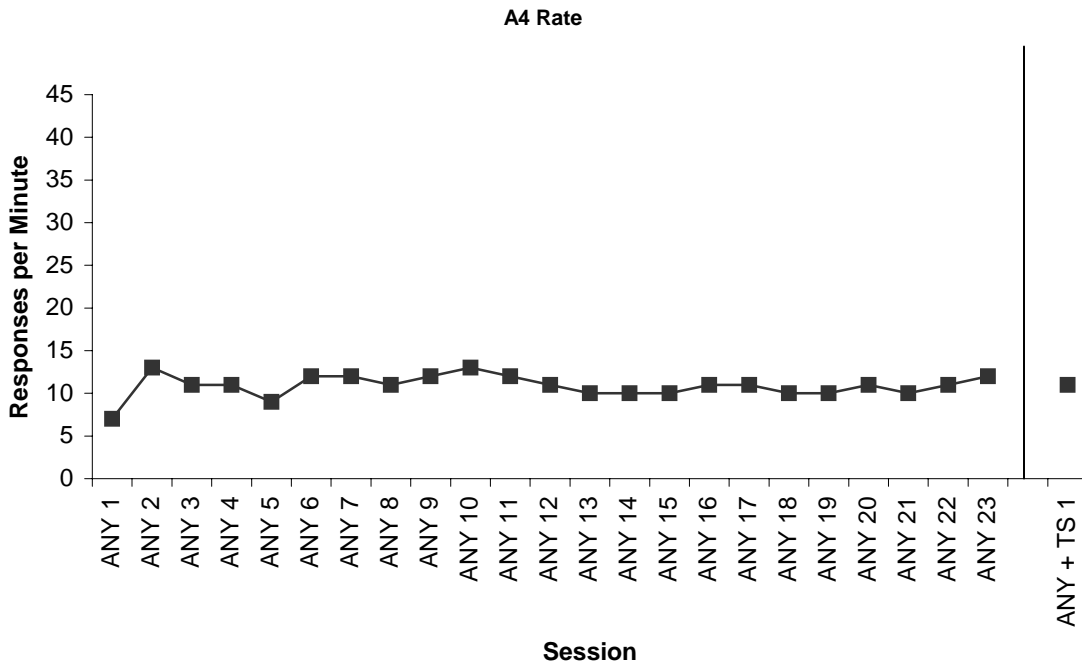Figure 23. Number of instances of the target sequence per session across conditions for subject A4

A4 Rate
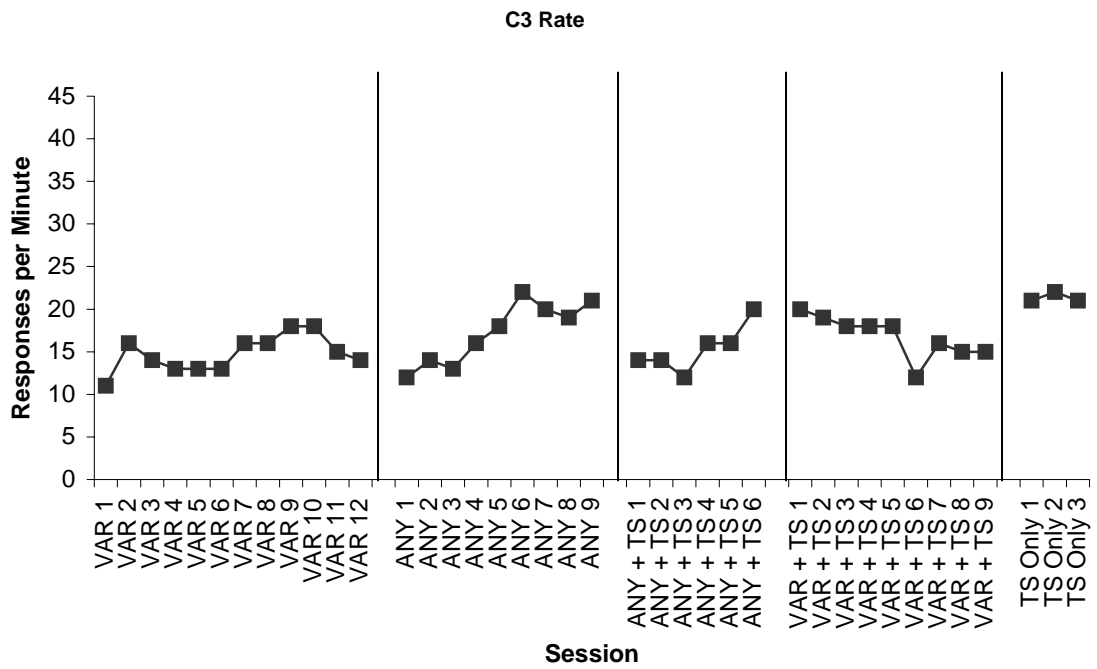

Figure 24. Number of trials per minute emitted by subject A4.

C3 Rate

Figure 25. Number of trials per minute emitted by subject C3.
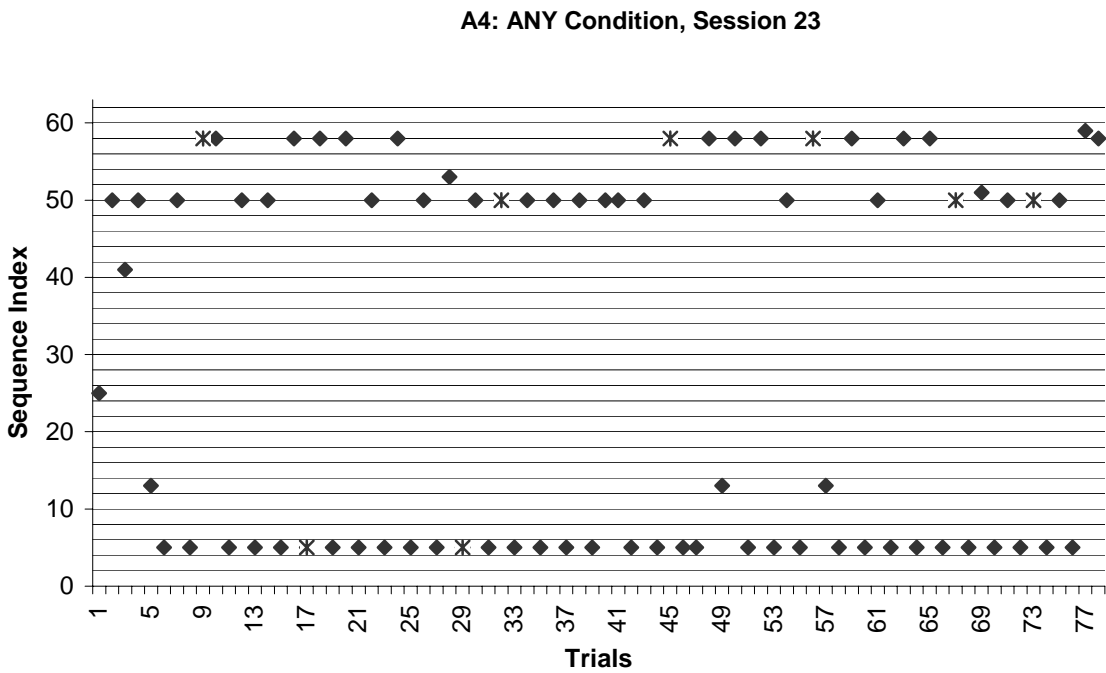
A4: ANY Condition, Session 23

 Figure 26. Sequences emitted by subject A4 during the session just prior to acquisition. Asterisks indicate reinforced sequences.
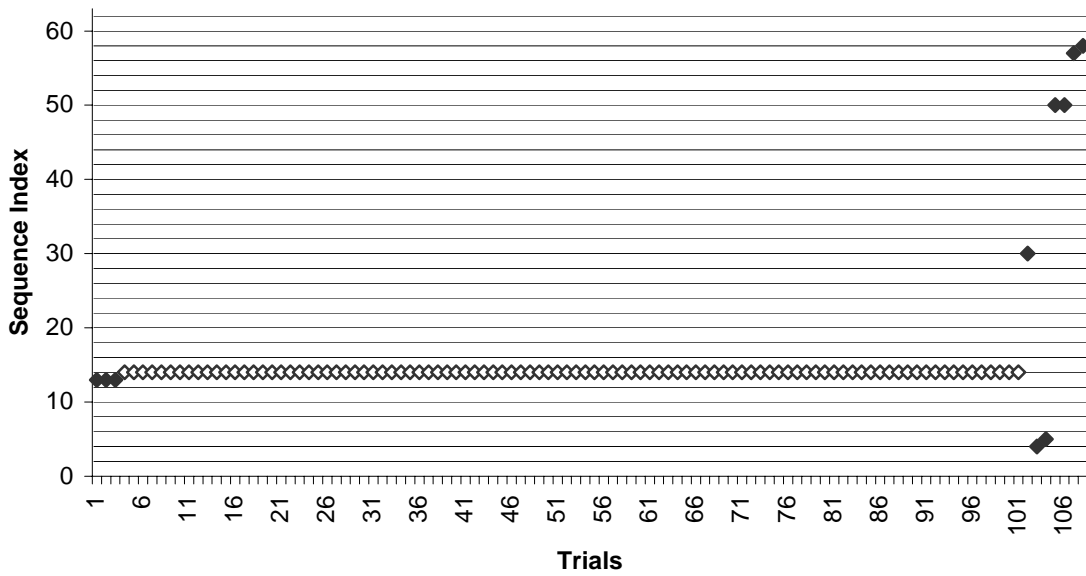
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A4: ANY + TS, Session 1

Figure 27. Sequences emitted by subject A4 the first session of the TS Only condition. The open diamonds indicates the target sequence (index number 14).
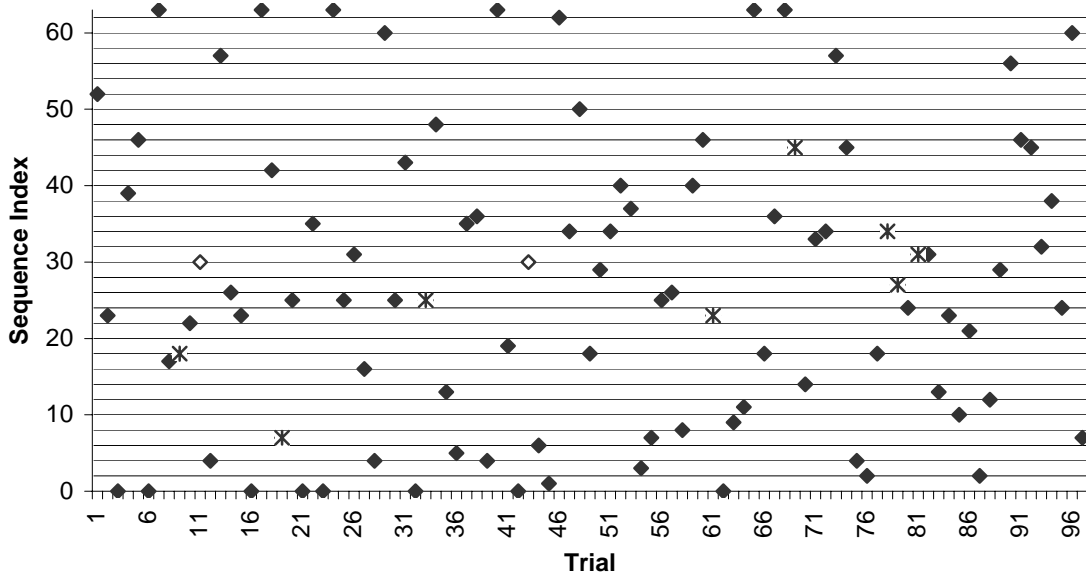
C3: VAR + TS, Session 10

Figure 28. Sequences emitted by subject C3 during the session with the highest variability measures of the Experiment 2. Asterisks indicate reinforced sequences; open diamonds indicate instances of the target sequence.

Sequence	Index	Sequence	Index	Sequence	Index	Sequence	Index
LLLLLL	0	LRLLLL	16	RLLLLL	32	RRLLLL	48
LLLLLR	1	LRLLLR	17	RLLLLR	33	RRLLLR	49
LLLLRL	2	LRLLRL	18	RLLLRL	34	RRLLRL	50
LLLLRR	3	LRLLRR	19	RLLLRR	35	RRLLRR	51
LLLRLL	4	LRLRLL	20	RLLRLL	36	RRLRLL	52
LLLRLR	5	LRLRLR	21	RLLRLR	37	RRLRLR	53
LLLRRL	6	LRLRRL	22	RLLRRL	38	RRLRRL	54
LLLRRR	7	LRLRRR	23	RLLRRR	39	RRLRRR	55
LLRLLL	8	LRRLLL	24	RLRLLL	40	RRRLLL	56
LLRLLR	9	LRRLLR	25	RLRLLR	41	RRRLLR	57
LLRLRL	10	LRRLRL	26	RLRLRL	42	RRRLRL	58
LLRLRR	11	LRRLRR	27	RLRLRR	43	RRRLRR	59
LLRRLL	12	LRRRLL	28	RLRRLL	44	RRRRLL	60
LLRRLR	13	LRRRLR	29	RLRRLR	45	RRRRLR	61
LLRRRL	14	LRRRRL	30	RLRRRL	46	RRRRRL	62
LLRRRR	15	LRRRRR	31	RLRRRR	47	RRRRRR	63

Table 2. Sequences with corresponding sequence index number.

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