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REINFORCER MAGNITUDE AND RESISTANCE TO CHANGE OF FORGETTING FUNCTIONS AND RESPONSE RATES

by

Meredith S. Berry

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Psychology

Approved:

Amy L. Odum Major Professor	Kerry E. Jordan Committee Member
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UTAH STATE UNIVERSITY
Logan, Utah

2012

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ABSTRACT

Reinforcer Magnitude and Resistance to Change of Forgetting Functions and Response Rates

by

Meredith S. Berry, Master of Science

Utah State University, 2012

Major Professor: Dr. Amy L. Odum
Department: Psychology

The present experiment was conducted to investigate the effects of reinforcer magnitude on resistance to disruption of remembering and response rates. Pigeons were exposed to a variable-interval (VI), delayed-matching-to-sample procedure (DMTS) with two components (rich and lean). Specifically, completion of a VI 20 second (s) multiple schedule resulted in DMTS trials in both components. In a DMTS trial, a choice of one of two comparison stimuli (e.g., blue key) results in reinforcement if the choice matches some property of the sample stimulus presented previously. Sample and comparison stimuli are separated by a delay. Four delays (0.1, 4, 8, and 16 s) were used between the sample and comparison stimuli in the study. The difference between rich and lean components was the length of hopper duration following a correct response. The probability of reinforcement following a correct response in both components

was .5. Each pigeon was exposed to 50 sessions of initial baseline and then 30 sessions of baseline between each disruptive condition (extinction, intercomponent interval [ICI] food, lighting the houselight during delays, and prefeeding). Separable aspects of the forgetting functions (initial discriminability and rate of forgetting) were examined by determining accuracy at each delay. During baseline, response rates were higher in the rich component relative to the lean. Accuracy decreased as delay increased in both rich and lean components, and accuracy was consistently higher in the rich relative to the lean component. During disruptive conditions, extinction, ICI food, and prefeeding disrupted response rates, but lighting the houselight during the delays had little effect. During the DMTS portion of the procedure, extinction and prefeeding decreased initial discriminability and lighting the houselight during the delay increased rate of forgetting. Intercomponent food had little effect on accuracy. Accuracy in the rich component was more resistant to disruption relative to the lean component during extinction. These results indicate that certain disruptors do not have the same disruptive effect across response rates and accuracy (e.g., ICI food). These data also suggest that when systematic differences in accuracy between rich and lean components are revealed, performance in the rich component tends to be more resistant to disruption.

(67 pages)

PUBLIC ABSTRACT

Reinforcer Magnitude and Resistance to Change of Forgetting Functions and Response Rates

by

Meredith S. Berry, Master of Science

Utah State University, 2012

Enhanced memory that is less susceptible to disruption has been demonstrated previously, by presenting more reinforcement for correct responses (e.g., a higher probability of reinforcement) in a conditional discrimination task. The purpose of the present experiment was to extend our current understanding of this phenomenon to a different dimension of reinforcement (i.e., magnitude). This would offer additional techniques for delivery of reinforcement within applied settings (e.g., a classroom) that could promote accurate and persistent memory. The present experiment, therefore, was conducted to investigate the effects of reinforcer magnitude on resistance to disruption of remembering and response rates. Pigeons were exposed to a variable-interval (VI), delayed-matching-to-sample procedure (DMTS) with two components (rich and lean). Specifically, completion of a VI 20-second (s) multiple schedule resulted in DMTS trials in both components. In a DMTS trial, a choice of one of two comparison stimuli (e.g., blue key) results in reinforcement if

the choice matches some property of the sample stimulus presented previously. The sample and comparison stimuli are separated by a delay. Four delays (0.1, 4, 8, and 16 s) were used between the sample and comparison stimuli in the present study, and were presented equally across rich and lean components. The difference between rich and lean components was the length of hopper duration (either 4.5 s [rich component] or 0.75 s [lean component]) following a correct response. After baseline performance was established, memory was tested with disruptive conditions (extinction, ICI food, lighting the houselight during delays, and prefeeding). Results showed that during baseline, accuracy was higher in the component with more reinforcement access (4.5 s) relative to the component with less (0.75 s), and accuracy decreased as delays increased in both components. Remembering was also more resistant to disruption in the component with more reinforcement access. These results suggest that providing greater length of access to reinforcement in applied settings may be an effective way to increase accuracy and persistence in memory.

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Meredith S. Berry

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INTRODUCTION

In general, memory tends to degrade with the passage of time. Reinforcement, however, can affect accuracy of remembering over time (Brown & White, 2009) and during disruption (Odum, Shahan, & Nevin, 2005). More reinforcement tends to increase accuracy of remembering, and also make remembering more resistant to disruption. Several theories have been proposed to explain the influence of reinforcement on remembering (e.g., Nevin, Davison, Odum, & Shahan, 2007; White & Wixted, 1985). One approach emphasizes concepts from behavioral momentum theory, highlighting the similarities between the effects of reinforcement on free operant behavior and conditional discrimination (e.g., Nevin, Davison, & Shahan, 2005).

Behavioral momentum theory states that a learned behavior, once reinforced, will tend to persist (Nevin, Mandell, & Atak, 1983), despite some degree of disruption (e.g., extinction). The persistence of such a response has been metaphorically likened to an object set in motion, which slows, and eventually stops with friction (Nevin, 1995). In fact, constant velocity has been compared to stable rates of responding under baseline conditions (Nevin & Grace, 2000). Another productive comparison of momentum theory to responding under constant conditions is the dissociation of response rates and resistance to change as separate measures of behavior.

A considerable amount of research has proven consistent with behavioral momentum theory and offers a useful conceptualization of understanding

reinforcement history and current behavior, including drug addiction and relapse (Quick & Shahan, 2009), resistance to change of behavior within rich and lean contexts (Podlesnik & Shahan, 2009), recovery of responding across training and extinction contexts (Bouton & Bolles, 1979) and resistance to change of discriminations by individuals with severe mental retardation (Dube & McIlvane, 2001). Behavioral momentum has typically been used to describe and understand the rate and resistance to change of free operant behavior. Less often investigated, however, is the paradigm of behavioral momentum applied to performance accuracy, which can be useful for studying remembering (i.e., delayed stimulus control; Odum et al., 2005), and conditional discrimination (Nevin, Milo, Odum, & Shahan, 2003).

Previous reports (e.g., Nevin et al., 2003) have indicated that accuracy is more persistent within a discrimination procedure with more reinforcement, just as the rate of responding within a free operant procedure. This finding suggests that the same principles that govern resistance to change with quantity of behavior (e.g., response rates), also determine how well a behavior is performed (e.g., accuracy). To extend the framework of behavioral momentum theory to remembering, Odum and colleagues (2005) arranged rich and lean contexts (using high and low probabilities) within a delayed-matching-to-sample (DMTS) task. Results showed that remembering was enhanced and less susceptible to disruption with additional reinforcement, suggesting better overall performance when accuracy is reinforced at higher rates.

Although enhanced remembering and resistance to disruption was observed in the research of Odum and colleagues (2005) using signaled probabilities of rich or lean reinforcement availability, these effects have not been tested across other dimensions of reinforcement (e.g., magnitude or quality), using the same disruptors. In order to establish generality of the effects observed in the research of Odum and colleagues, this study addressed the influence of magnitude of reinforcement using a similar procedure as Odum and colleagues. Magnitude in this case refers to the length of time that the reinforcer (i.e., food) was presented. Thus, we presented a stimulus during the retention interval that signaled the magnitude of available reinforcement upon a correct response. When the signaling stimulus was one color (e.g., center key red) during the retention interval, a correct response resulted in 4.5-second (s) access to food, whereas if the signaling stimulus was another color (e.g., center key green), a correct response resulted in 0.75-s access to food. Following baseline conditions, disruptors used previously (i.e., Nevin & Grosch, 1990; Odum et al., 2005) were presented to assess the relative resistance to disruption of remembering across the rich and lean components.

Therefore, the purpose of the present study was to test signaled magnitude of reinforcement within a DMTS preparation to extend our current understanding of varying reinforcement dimensions and subsequent effects on initial discrimination, forgetting functions, and resistance to change of remembering. Increased accuracy during baseline within the rich component

(4.5-s access to food), relative to the lean component (0.75-s access to food), would show that greater magnitudes of reinforcement facilitate enhanced remembering in this specific DMTS procedure. Additionally, if enhanced remembering were more resistant to change in the rich component relative to the lean during phases of disruption, this would indicate initial conditions of training with greater magnitudes of reinforcement facilitate greater persistence of remembering.

LITERATURE REVIEW

Behavioral momentum theory states that a learned behavior, once reinforced, will tend to persist (Nevin et al., 1983), despite some degree of disruption (e.g., extinction). Data from a number of studies suggest that reinforcement conditions prior to the presentation of a disruptor directly affect the persistence of responding (e.g., Nevin, 1974; Podlesnik & Shahan, 2009). Specifically, behavior that has been richly reinforced tends to be more resistant to disruption. Behavioral momentum theory offers a fruitful conceptualization of the persistence of human responding despite disruption (e.g., extinction, distraction) and has proven useful in understanding persistence of behavior despite negative consequences as in cases of drug addiction and relapse (Quick & Shahan, 2009; Shalev, Highfield, Yap, & Shaham, 2000). Additionally, greater persistence of behavior resulting from richer schedules of reinforcement has been demonstrated across many species and situations, using various disruptors (e.g., Dube & McIlvane, 2001; Harper, 1996; Mace et al., 1990).

Behavioral momentum has typically been used to describe and understand the rate and resistance to change of free operant behavior. Less often investigated, however, is the paradigm of behavioral momentum applied to performance accuracy, which can be useful for studying remembering (i.e., delayed stimulus control; Odum et al., 2005), and conditional discrimination (Nevin et al., 2003). Previous reports (e.g., Nevin et al., 2003) have indicated that accuracy is higher and more persistent within a discrimination procedure using

richer schedules of reinforcement just as persistence in rates of responding is within a free operant procedure. This suggests that the same principles that govern resistance to change with quantity of behavior (e.g., response rates), also determine how well a behavior is performed (e.g., accuracy). Further developing these methods could offer additional techniques for delivery of reinforcement within applied settings (e.g., a classroom) as well as extend the utility of the theory of behavioral momentum.

Behavioral Momentum

Behavioral momentum theory states that behavior tends to repeat in the presence of the same antecedent stimuli in which it was learned, despite some disruption (Nevin et al., 1983). Nevin and Grace (2000) described response rate and persistence as separable aspects relating to the strength of a behavior. In fact, it is suggested by Nevin and colleagues (1983) that performance is characterized by response rates, but resistance to change could be an indicator of learning. Resistance to disruption of a behavior offers another measure of relative strength in addition to response rate, which is a conditionable aspect of behavior. That is, responding that is reinforced more richly in the presence of one stimulus (e.g., green key color), will tend to persist to a greater degree relative to baseline than responding that was less reinforced in the presence of another stimulus (e.g., red key color) upon disruption.

Researchers investigating behavioral momentum generally employ a

multiple schedule paradigm of free-operant responding (e.g., key-pecking), using variable interval (VI) reinforcement schedules. A VI schedule of reinforcement requires a single response to collect the reinforcer, which becomes available after variable intervals, and engenders moderate steady rates of responding. In a multiple schedule, two VI schedules (e.g., VI 30-s, VI 120-s) alternate across a session, each with a distinctive stimulus (e.g., different key color). In the presence of one stimulus (e.g., red key light) a VI 30-s (rich) schedule is in place, in which key pecking results in access to food once every 30 s on average. Following the completion of that component, the other schedule, a VI 120-s (lean) schedule, occurs in the presence of a different stimulus (e.g., green key light), in which key pecking results in food once every 120 s on average. Thus, in the presence of one key color (i.e., the rich component) responding results in relatively more hopper deliveries and in the presence of the other key color (i.e., the lean component), key pecking results in relatively fewer hopper deliveries. Conventionally, researchers have used greater rates (e.g., Podlesnik & Shahan, 2009), longer access (Harper & McLean, 1992), or higher probabilities of reinforcement delivery (e.g., Odum et al., 2005) to make one schedule of reinforcement richer than another. Once rates of responding become stable, the strength of performance in each component is tested with disruption (e.g., Nevin, 1974; Nevin et al., 2003).

Some typical methods used to disrupt behavior in laboratory animals are extinction, prefeeding and intercomponent interval (ICI) food delivery. Extinction,

for example, involves discontinuing access to food and food-related stimuli for responses. With prefeeding, the subject is given a substantial amount of food in the home cage shortly before the experimental session. Free presentations of food between components, regardless of responding, occur during ICI food delivery. The presentation of disruption offers a measurement of persistence of the behavior, both compared to baseline levels of responding, and across rich and lean components.

One classic example of greater resistance to change in a more richly reinforced context is offered by Nevin (1974). In this series of experiments using pigeons as subjects, Nevin tested resistance to disruption of key pecking reinforced by access to grain within rich and lean components of a multiple schedule. Specifically, resistance to disruption was tested using extinction and response-independent food delivery. As free food rates increased, rates of responding decreased and proportion of baseline responding was greater in the rich schedule (VI 1-min) relative to the leaner schedule (VI 3-min). Extinction produced similar results. Experiment 2 employed a similar multiple schedule (mult VI 2-min and VI 6-min) and similar results were obtained with tests of extinction. That is, responding in the presence of the key light previously associated with the VI 2-min schedule was more resistant to extinction than responding in the presence of the key light previously associated with the VI 6-min schedule.

Experiment 3 of Nevin (1974) investigated further resistance to change by

varying the magnitude of reinforcement rather than reinforcement rate and then challenging performance with response independent food in another third component. Results showed that response rates were reduced relative to baseline more in the leaner component (2.5 s access to grain) relative to the richer component (7.5 s access to grain), regardless of relative response rates observed during baseline. Thus, similar results were obtained when the magnitude was varied as compared to rate of reinforcement. That is, when responding was disrupted by response independent food, resistance to change was greater in the rich schedule relative to the lean.

To summarize, these findings demonstrate that when previously reinforced at a greater rate or magnitude, responding will be more resistant to disruption than with relatively less reinforcement. This phenomenon tends to occur regardless of baseline response rates. This effect has been explicitly investigated with response independent food provided in the rich component of a multiple schedule, driving response rates in the rich component below response rates in the lean component (e.g., Nevin, Tota, Torquato, & Shull, 1990; Podlesnik & Shahan, 2009). Despite lower response rates during baseline, responding in the rich component is more persistent upon disruption than responding in the lean component. Thus, greater degrees of persistence in more richly reinforced contexts seem to be robust to different baseline preparations of free operant behavior.

Greater resistance to change of behavior following greater rates of

reinforcement has been demonstrated across a number of species including rats (Quick & Shahan, 2009), pigeons (Podlesnik & Shahan, 2009) and humans with severe mental retardation (Dube & McIlvane, 2001), and has implications for human maladaptive behavior. Accordingly, the conceptualization of behavioral momentum can be useful in understanding the acquisition and persistence of adaptive and maladaptive behavior. For example, better understanding the conditions in which self-control is formed and sustained could lead to better techniques of developing and maintaining self-control. Relatedly, implications for clinical interventions and drug addiction could result from a more comprehensive understanding of the influence of histories of reinforcement as related to different environmental cues and persistence of maladaptive behavior (Nevin & Grace, 2000). Although greater resistance to change with rich reinforcement has been frequently demonstrated in free operant preparations providing implications for human behavior, less often investigated is if similar baseline preparations and resistance to disruption of more complex cognitive tasks such as conditional discrimination (e.g., delayed-matching-to-sample) would also follow similar principles.

Delayed-Matching-to-Sample

DMTS procedures are commonly employed to study memory (e.g., Berryman, Cumming, & Nevin, 1963; Blough, 1959; White, 1985). In a standard DMTS paradigm the subject is presented with a sample stimulus (e.g., red center

key). Following an observing response the sample is terminated and a delay (i.e., the retention interval) is initiated, after which the subject chooses between two comparison stimuli, one that matches the physical properties of the sample stimulus, and one that does not. A response to the comparison stimulus which matches the sample (e.g., red key) results in access to food, and a response to the comparison that does not match the sample (e.g., green key) results in blackout. As retention intervals increase (e.g., from 1 s to 15 s) accuracy tends to decrease, producing a forgetting function with high discrimination at short delays (e.g., 0 s) and lower discrimination at longer delays (e.g., 15 s). One method that is often used to calculate discrimination in DMTS procedures is log *d*. Log *d* is calculated by taking the logarithm of the geometric mean of the ratio of correct to error responses following each sample (Davison & Tustin, 1978):

$$\log d = 0.5 * \log [(c_r / e_r) * (c_g / e_g)], \quad (1)$$

where c_r, and c_e denote correct and error responses to the red sample, and c_g and e_g denote correct and error responses to the green sample, respectively.

White (1985, 2001) noted two separable aspects of forgetting functions: initial discriminability (accuracy at 0-s delay) and the rate of forgetting (slope of the function). Although some manipulations affect initial discriminability, other manipulations affect the slope of the function. For example, the number of observing responses (i.e., pecks to the sample stimulus) increases accuracy at 0-s delay and therefore increases discriminability, but has no effect on rate of forgetting. Lighting the houselight during the retention interval, however, increase

the rate of forgetting (slope), but has little effect on initial accuracy (e.g., White, 1985).

One well established finding, known as the signaled magnitude effect, reveals that initial discriminability is higher (though slope is unchanged) when relatively greater within-session reinforcer magnitudes (Brown & White, 2009, 2011; Jones, White, & Alsop, 1995; Nevin & Grosch, 1990), or higher probabilities (Brown & White, 2009; White & Wixted, 1985) of reinforcement are provided. That is, initial discriminability increases with relatively greater amounts of reinforcement, but the rate of forgetting (slope) remains unaffected by these conditions. Although the signaled magnitude effect occurs with both greater magnitudes and higher probabilities of reinforcement, the effect of frequency of reinforcement has been reported to be stronger than the effect of magnitude (e.g., Boldero, Davison, & McCarthy, 1985). There is a paucity of research, however, on the influence of such baseline conditions (i.e., magnitude) upon disruption of delayed-matching-to-sample performance.

Although delayed-matching-to-sample procedures are frequently used to assess environmental and pharmacological effects on remembering (Kangas, Berry, & Branch, 2011), less research has been conducted on how the effects of baseline conditions influence resistance to disruption of remembering (Odum et al., 2005). Nevin and colleagues (2003) investigated whether similar principles that govern resistance to change in the well-documented free-operant procedures also govern conditional discrimination performance. More explicitly,

Nevin and colleagues explored whether the conditions which make response rates in a free operant procedure more persistent also make conditional discrimination more persistent in a delayed-matching-to-sample procedure using prefeeding, intercomponent food delivery, introduction of a retention interval, and extinction as disruptors. To test this, Nevin and colleagues evaluated response rates and delayed-matching-to-sample performance using pigeons with one retention interval (0-s) and multiple components (each VI 30-s), signaling rich (0.8 probability of reinforcement) and lean (0.2 probability of reinforcement) components. Following baseline conditions, resistance tests were introduced. Again, prefeeding, intercomponent food delivery, introduction of delay between sample and comparison stimuli, and extinction were used to examine resistance to change. With few exceptions, response rates and matching accuracy in the rich component were more resistant to disruption than response rates and matching accuracy in the lean component.

These data suggest that resistance to change of conditional discrimination performance may operate similarly to free operant responding. That is, the well-established findings that greater rates of baseline reinforcement lead to higher response rates and greater resistance to change, also apply to resistance to change of conditional discrimination performance. Relatively higher baseline rates of reinforcement, therefore, produce not only more behavior that is more resistant to disruption, but also enhanced performance that is more resistant to disruption. Although Nevin and colleagues (2003) demonstrated that accuracy

was higher and more persistent with greater reinforcement probabilities, only one retention interval (0 s) was used.

Odum and colleagues (2005) employed a similar procedure but with several retention intervals. This experiment was conducted to investigate how relatively rich and lean baseline conditions affect forgetting functions across a range of retention intervals upon disruption. Using different colored key lights to signal rich (0.9) and lean (0.1) probabilities of reinforcement following a correct match, Odum and colleagues used a similar VI-DMTS procedure as Nevin and colleagues (2003). That is, a VI schedule was in place on the center key and provided access to a DMTS trial. Intercomponent food delivery, prefeeding 30 min prior to session, and extinction were used as disruptors following baseline, to test persistence of response rates and accuracy. Log *d* values (Equation 1) were calculated for each subject at each retention interval and for rich and lean components across baseline and disruptive phases.

Results showed that baseline response rates and levels of accuracy as measured by log *d* were higher in the rich condition (with 0.9 probability of reinforcement) than the lean condition (with 0.1 probability of reinforcement). Disruption by ICI food and extinction reduced response rates more in the lean condition than the rich condition. Log *d* values revealed that ICI food increased the rate of forgetting (slope) but did not systematically affect initial discriminability. Extinction, however, reduced initial discriminability more in the lean component that the rich component, but did not affect the rate of forgetting.

Thus, these specific disruptors had different effects on the forgetting functions generated by this VI-DMTS procedure.

Although enhanced and more persistent remembering was observed in the research of Odum and colleagues (2005) using signaled probabilities of more or less reinforcement availability, other dimensions of reinforcement (e.g., magnitude or quality) using similar procedures have not been tested in DMTS performance using the same disruptors. Effects of motivational disruptors (e.g., prefeeding) and distraction disruptors (e.g., Nevin & Grosch, 1990) have also not been effectively tested across a range of retention intervals in a VI-DMTS procedure. Therefore, testing signaled magnitude of reinforcement within a remembering task would extend our current understanding of dimensions of reinforcement and how these dimensions affect accuracy upon exposure to extinction, ICI food delivery, lighting the houselight during delays, and prefeeding.

Theories of Delayed-Matching-to-Sample Performance

One integrative theory that is able to account for some effects of reinforcement on DMTS performance is that proposed by White and Wixted (1985). This theory incorporates remembering in DMTS procedures with the matching law. The matching law states that behavior is allocated in proportion to rates of reinforcement associated with concurrent choice alternatives (Baum, 1974; Herrnstein, 1961; Koffarnus & Woods, 2008). White and Wixted note that each stimulus in a DMTS task is associated with a ratio of reinforcers obtained

for correct choices (of the comparison stimuli). The ratio of reinforcers, which is based on the matching law and dictates choice, is established by experience with these stimuli for prior correct choices. This model predicts that biasing effects of the reinforcement ratio can occur. In other words, choice proportions will match the ratio of reinforcers. For example, if more reinforcement has been obtained previously for choices to the green comparison stimulus, a subject may be more likely to choose the green comparison stimulus in the future, whether or not it is the correct response. These biasing effects tend to be enhanced with longer delays and decreased discriminability. Choice behavior is therefore dictated by an individual's history of reinforcement. Delayed-matching-to-sample data are generally well described by this model.

Although DMTS data generally conform to the model proposed by White and Wixted, the model fails to account for increased accuracy resulting from increased levels of reinforcement across contexts. Brown and White (2009) added reinforcement context in a later version of the model, which helps to account for this effect. Delayed-matching-to-sample performance during disruption, however, is not addressed by White and Wixted's model.

One influential theory, postulated by Nevin and colleagues (2005), does account for the effects of different levels of reinforcement across contexts in conditional discrimination procedures with no delay between sample and comparison stimuli. This theory asserts that the probability of attending is influenced by reinforcement in the same way that free operant behavior is. In

other words, attending to sample and comparison stimuli, and resulting levels of accuracy and resistance to disruption, conform to predictions derived from behavioral momentum theory. The more reinforcement (e.g., greater probability of reinforcement) provided for a correct response the more accurate and persistent matching-to-sample performance will be.

Nevin and colleagues (2007) expanded this theory to include the effects of reinforcement on remembering. Similar to the previous theory and following from concepts of behavioral momentum, the probability of attending to the sample and comparison stimuli independently, and the persistence of accuracy upon disruption, are influenced by levels of reinforcement. In other words, attention to stimuli is enhanced and more persistent in a context associated with relatively more reinforcement. This theory included working memory by accounting for disruption of attending that occurs as a result of the delay between sample and comparison stimuli in DMTS procedures. Taking into account the influence of varied reinforcement across contexts, and the disruption of delay between the sample and comparison stimulus on attending, this theory is able to account for DMTS data (e.g., higher accuracy with more reinforcement) better than some preceding theories. This theory also accounts for the effects of disruption (e.g., extinction) on DMTS performance.

Although this experiment was not designed to test these theories, the data were expected to generally conform to predictions of the theory proposed by Nevin and colleagues (2007) within a VI-DMTS procedure. That is, performance

was expected to be more accurate during baseline and persistent during disruption in the rich component relative to the lean. Additionally, the majority of the predictions proposed by Nevin and colleagues in the 2007 model were made on the basis of differing reinforcement probabilities to establish rich and lean contexts, rather than differing magnitudes. Examining the effects of magnitude within a VI-DMTS procedure across rich and lean components may offer new insight into the generality of the model.

Divergent Findings

Previous researchers have investigated the effects of differing magnitudes on DMTS performance, but have used a different procedure than the one proposed for this study (i.e., signaled DMTS as opposed to VI DMTS). Nevin and Grosch (1990) investigated the effects of differing magnitudes of reinforcement on resistance to change of forgetting functions using pigeons, but used different disruptors than those described previously. Specifically, Nevin and Grosch used houselight and sample alterations, and drug administration as disruptors. Distinct sounds signaled either large or small reinforcer magnitudes (4.5- or 1.5-s access to grain). Performance was disrupted by presenting the houselight during the retention interval, injections of sodium pentobarbital, and sample duration reduction. Although baseline accuracy was higher with larger magnitudes (i.e., longer hopper duration), no difference was found between the large and small signaled magnitude forgetting functions upon disruption when analyzed relative

to baseline performance (logit p in disruption tests over logit p in baseline). These results were not consistent with the typical results found when investigating persistence of behavior in free-operant preparations. Although it is possible that the divergent findings of Nevin and Grosch were due to the different disruptors used, it is also possible that using magnitudes of reinforcement, instead of probabilities of reinforcement, could have different effects on resistance to change of forgetting functions. A third possibility is that the use of sound (i.e., tone and white noise) to signal the difference in magnitudes across components, contributed to the divergent findings. Specifically, the disruptors may have diminished control by the auditory component stimuli, which are not often used with pigeons, and thus diminished the influence of reinforcer magnitude on persistence.

Another potential reason results of Odum and colleagues (2005) differed from those of Nevin and Grosch (1990) could be related to the difference in trial structure across procedures (Nevin, Shahan, Odum & Ward, 2011). In the VI-DMTS procedure used in the Odum and colleagues, multiple VI schedules across rich and lean components led to DMTS trials. The reinforcer probabilities were signaled throughout the component (before the sample presentation, during the delay), which consisted of four trials. Alternatively, in the signaled-DMTS-trials procedure employed by Nevin and Grosch, the reinforcer magnitude was signaled at sample onset and through the retention interval, and small and large magnitude trials alternated irregularly. The differences across procedures (e.g.,

delays, disruptors, probability versus magnitude, trial structure), however, create difficulties in isolating the causes of these discrepant results.

To address these issues, Nevin and colleagues (2011) standardized the different but related DMTS tasks using the same delays and disruptors, and similar probabilities to establish rich and lean contexts across experiments. Results showed that the proportion of baseline log *d* values for rich probability trials in the VI-DMTS procedure (similar to Odum et al., 2005) were more resistant to disruption during extinction and prefeeding. Proportion of baseline log d values for lean probability trials in the signaled-DMTS-trials procedure (similar to Nevin & Grosh, 1990), however, were more resistant to these disruptors. Therefore, opposite results were obtained across these standardized procedures, generally replicating previous findings.

The differences in resistance to disruption across rich and lean contexts in the VI-DMTS and the signaled-DMTS procedures can be explained by the aforementioned theory proposed by Nevin and colleagues (2007). In the VI-DMTS procedure, the reinforcer probabilities across rich and lean components are signaled throughout the DMTS portion of the procedure, as well as the VI portion. In contrast, in the signaled DMTS procedure, the reinforcer probabilities are only signaled during DMTS trials. As proposed by Nevin and colleagues, attention to the sample is influenced by signaling rich or lean probabilities. Therefore, if rich and lean probabilities are signaled more during the VI-DMTS procedure, then attention to the sample across rich and lean trials is

differentiated more in the VI-DMTS than signaled DMTS procedure. On the other hand, the probability of attending to the comparison stimuli (a separate process) is differentiated more in the signaled-DMTS than VI-DMTS procedure (see Nevin et al., 2011, for exact calculations of each parameter and probabilities of attending to sample and comparison stimuli). These reasons may also help explain the differences in proportion baseline log d values during disruption found between VI-DMTS and signaled-DMTS procedures.

The present experiment was designed to test the effects of magnitude of hopper duration (i.e., longer versus shorter hopper durations) on forgetting functions within a similar VI-DMTS procedure as used in Odum and colleagues (2005). The disruptors used were expected to influence performance in a number of different ways. For example, some were expected to affect motivational factors (e.g., ICI food), and others were expected to distract from the DMTS task (e.g., houselight alterations). Additionally, some disruptors were directly related to the contingencies of reinforcement (e.g., extinction), which may differentially impact resistance to change of the forgetting functions. Thus, various disruptors were selected for the present experiment, in order to test different effects on resistance to change of DMTS performance when magnitude is used to establish rich and lean contexts.

STATEMENT OF THE PROBLEM

Numerous studies have documented greater resistance to disruption of behavior in a free-operant procedure as a result of richer reinforcement delivery during baseline (e.g., Nevin, 1974; Podlesnik & Shahan, 2009). This phenomenon has implications for the persistence of adaptive as well as maladaptive behavior (Nevin & Grace, 2000). Although a great deal of inquiry has been devoted to baseline conditions and the persistence of free operant behavior, few studies have explicitly investigated the resistance to change of conditional discrimination (Odum et al., 2005) or more complex patterns of responding (Berryman et al., 1963).

Odum and colleagues (2005) extended research on resistance to change of rich and lean baseline reinforcer delivery to delayed-matching-to-sample performance across a range of retention intervals. Specifically, Odum and colleagues investigated response rates and forgetting functions resulting from relatively high and low baseline reinforcer probabilities within a VI-DMTS procedure. Subsequent effects of disruption on response rates and forgetting functions were assessed. Similar to the effects observed using free operant procedures, accuracy tended to be more persistent in the rich conditions relative to the lean upon disruption. It has not currently been tested, however, if the same effect would occur across other dimensions of reinforcement (e.g., magnitude or quality) within a VI-DMTS procedure. Therefore, we established rich and lean schedules by varying magnitude, and disrupted performance by using the same

methods of Odum and colleagues. That is, extinction and ICI food were used. This allowed a comparison of the effects of disruption on behavior maintained by rich and lean schedules established by reinforcer probability (e.g., Odum et al., 2005) and by reinforcer magnitude (present experiment). In addition to testing the disruptors used previously in the work of Odum and colleagues, prefeeding and houselight alterations (Nevin & Grosch, 1990) were also used to disrupt performance. Nevin and Grosch used houselight manipulations as one disruptor and found no consistent differences between behavior maintained by rich and lean schedules established by magnitude. Thus, testing the same disruptor within the VI-DMTS procedure may provide insight into these results. Therefore, the purpose of the present experiment was to investigate the effects of signaled large and small magnitudes of reinforcement on forgetting functions both in baseline and during disruptive phases, using a variety of disruptors.

METHOD

Subjects

Four homing pigeons with previous experimental history were used in the present experiment. Each pigeon had previous experience with VI schedules of food delivery and extinction. The pigeons were maintained at 80% of their free-feeding weights by post-session feeding as needed. Pigeons were housed in individual cages in an AAALAC-accredited facility, in a temperature- and humidity-controlled colony room, with exposure to a 12:12-hr light/dark cycle. Water was available continuously in their home cages.

Apparatus

Four BRS/LVE operant chambers within sound-attenuating enclosures were used. Each chamber was 30.7-cm long, 35-cm wide, and 35.8-cm high. Three translucent keys were located on the front panel (intelligence panel), each measuring 2.6 cm in diameter and 24.6 cm from the floor. Each key could be lit red, green, yellow or blue. Keys required a minimum force of 0.10 N to operate. The houselight was centered at the top of the front wall, 4.4 cm above the center key. Located 9 cm below the center key light was the hopper where pigeon chow was presented with a white light. Med-Associates interfacing and an IBM computer recorded experimental events in an adjacent room.

Procedure

Due to their prior experimental history with VI schedules, the pigeons were exposed directly to the VI-DMTS procedure. Figure 1 presents a schematic diagram of the procedure. This procedure was designed to study DMTS performance across rich and lean schedules within a VI multiple schedule. Specifically, a two component multiple schedule was signaled by the center key color (red or green; Red is used in Figure 1 as an example). Pecks to the lit center key produced DMTS trials on a VI 20 s schedule. A DMTS trial began with a lit yellow or blue center key. The yellow or blue sample terminated after 6 s or on the first peck after 3 s. The center key was then lit the same color (red or green) present during the VI portion of the procedure. The center key remained lit during a delay of 0.1, 4, 8 or 16 s (similar to the range of retention intervals used in Kangas et al., 2011; White, 1985). Each delay was presented 8 times per session in each component of the multiple schedule.

Following the delay, the center key was darkened and the comparison keys were lit (yellow or blue). The configuration of the comparison stimuli varied randomly across trials. A response to the comparison key that matched the sample produced food or blackout with a probability of .5 in both components of the multiple schedule. The components differed by length of hopper presentation (magnitude). The red or green light represented the relatively rich component (4.5 s access to grain) or the relatively lean component (0.75 s access to grain) at the beginning of each trial and during the delays. This six-fold difference in

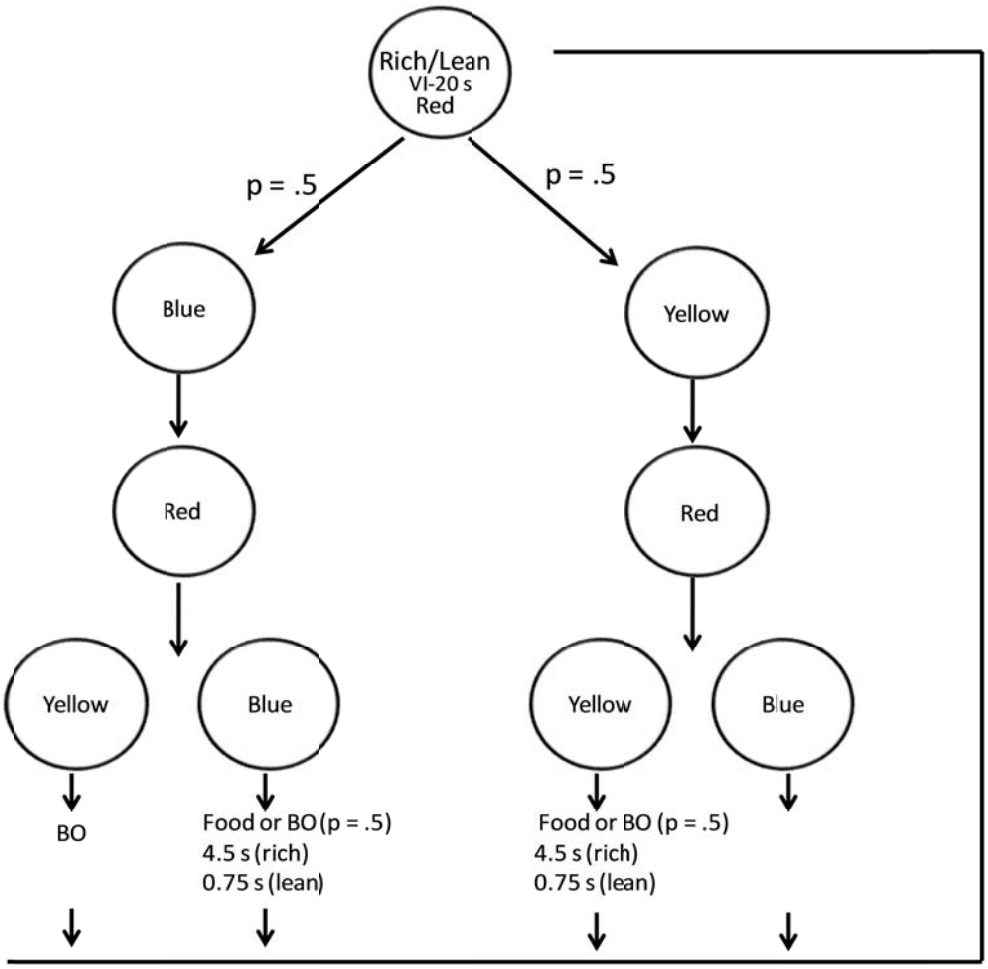

Figure 1. Schematic diagram of the VI-DMTS procedure. A key labeled red is used to represent the VI portion of the procedure in this diagram, but the key could also be green (depending on the rich or lean component). Pecks to the red or green center key produced a DMTS trial on a VI 20-s schedule. The DMTS trial began with a yellow or blue sample key. After 3-s and a peck to the sample stimulus, or 6-s had elapsed, a delay of 0.1, 4, 8 or 16 s was initiated. During this delay, the center key was illuminated (red or green). When the delay was complete, the center key darkened, and the comparison keys were illuminated yellow and blue. In the rich component, a peck on the matching side key produced 4.5 s access to the hopper or blackout with a probability of .5. In the lean component, a peck on the matching side key produced 0.75 s access to the hopper or blackout with a probability of .5. Nonreinforced pecks to the matching side key and all pecks to the nonmatching side key produced a blackout period. The center key was lit (red or green) for the VI portion of the procedure following food or blackout. See text for details.

magnitude was slightly greater than used in some previous reports (e.g., Brown & White, 2009; Harper & McLean, 1992; Nevin & Grosch, 1990), and was selected to establish a distinct disparity between hopper presentation durations across rich and lean contexts. Signaling the magnitude of reinforcement during the retention interval was expected to produce elevated accuracy in the condition with longer reinforcer access. The key light (red or green) and the component association (rich or lean) was counterbalanced across birds.

In order to equate time across the two components, 5 s elapsed until the next trial, regardless of component. A correct response in the rich component resulted in 4.5 s hopper access followed by 0.5 s blackout period before the next trial was initiated, and in the lean component, a correct response resulted in 0.75 s hopper access followed by a 4.25 s blackout period before the next trial was initiated. In both components, a correct response resulted in reinforcement 50% of the time. A blackout period of 5 s occurred in both components after an incorrect or nonreinforced response.

The component (rich or lean) was randomly selected at the onset of each session, and alternated for the remainder of the session. Each component was separated by a 15 s ICI in which the keys were dark and the houselight was lit. Components changed after four trials and were in effect for a minimum of approximately 90 seconds (although this time could vary substantially depending on the length of the VI portion). Each session consisted of 64 trials (half rich and half lean). Each pigeon was exposed to 50 sessions of initial baseline and 30

baseline sessions between each disruptive condition (similar to Odum et al., 2005). Data from the last 10 sessions of baselines were used for data analyses.

Resistance Tests

To examine resistance to change of accuracy and response rates, the following disruptors were presented in this order for each subject: extinction, ICI food, a lit houselight during the delays, and prefeeding (e.g., Nevin, 1974; Nevin & Grosch 1990; Nevin et al., 2003). Each disruptor was presented for 10 consecutive sessions, with separation of 30 baseline sessions between each disruptor (similar to Odum et al., 2005).

During extinction, correct pecks to the comparison stimulus did not result in access to the hopper, but instead in a blackout period (5 s for each component). If a comparison was not chosen within 15 seconds of presentation, a blackout period ensued, followed by the next trial. During extinction, not all 64 trials were completed by each subject. Subject 353 completed at least 40 trials during the first three sessions of extinction, and at least 15 trials during all subsequent extinction sessions. Subject 284 completed at least 60 trials during the first five sessions of extinction, and at least 33 trials during the last five sessions of extinction. Subject 232 completed at least 30 trials during the first five sessions of extinction, and at least 14 trials during the last five sessions of extinction. Subject 222 completed at least 63 trials during the first six sessions of extinction, and at least 17 trials during the last four sessions of extinction.

During the next disruptive condition (ICI food), food was presented during the ICI on a random time (RT) 5-s schedule (food was presented every 5 seconds, on average). During this disruptor, most or all trials were completed by each subject. Subjects 353, 284, and 222 completed all trials during all sessions of ICI food. Subject 232 completed at least 63 trials during all sessions.

During the following disruptive condition (lit houselight during delays), the houselight was lit during the retention interval. During this disruptor, most or all trials were completed by each subject. Subjects 284, 232, and 222 completed all trials during all sessions of the lit houselight during delays. Subject 353 completed at least 62 trials during all sessions.

During the next disruptive condition (prefeeding) each subject was fed 30 grams of food 30 min prior to session. During this disruptor, not all trials were completed by each subject. Subject 284 completed all trials during all sessions. Subject 222 completed at least 62 trials during all sessions. Subject 353 completed at least 20 trials during all prefeeding sessions. Subject 232 completed at least 63 trials during the first 6 sessions, and at least 16 during the final 4 sessions. To ensure that including all sessions (even those with fewer trials completed) did not impact data analyses, a criterion was selected for session omission. The criterion was that if less than 30% of trials were completed during a session that session was excluded from analysis. Across all subjects and disruptive conditions, this resulted in only seven sessions omitted from analysis. Because results were similar whether these sessions were omitted or

not, data for all subjects and sessions for each disruptive condition were used in the data analysis presented here.

Data Analysis

The primary dependent measures of interest in the present study were response rates during the VI portion of the schedule and accuracy at each delay (log *d*) during the DMTS portion of the schedule. Response rates were calculated as the number of responses per minute during the rich and lean VI components separately. Response rates were averaged over the last 10 days of each baseline condition. To examine if response rates were different across rich and lean components, and across successive baseline conditions, a two-way (component x condition) repeated measures analysis of variance (ANOVA) was performed.

To examine the effects of each disruptor, response rates in the rich and lean components were compared across baseline conditions and during each disruptive phase (extinction, ICI food, lit houselight during delays, and prefeeding) for each individual subject. More specifically, response rates were averaged over the last 10 days of baseline for rich and lean components separately. This was also done for the last 10 days of each disruptor. A paired *t* test was then used to test whether the proportion of baseline response rates during each disruptive phase was significantly different across rich and lean components. This offered a detailed account of potential differences in disruptive

effects across rich and lean components.

In addition to response rates, forgetting functions were also examined. In order to examine disruptive effects, forgetting functions across baseline and disruptive phases were compared. To do this, accuracy measures (log *d*) at each delay were pooled for rich and lean components separately for each subject over the last 10 sessions of each baseline condition. The same was done for the last 10 sessions of each disruptive condition. To examine initial discriminability (*a*) and rate of forgetting (*b*) across baseline and disruptive conditions, parameter values were generated using the exponential decay model (White, 2001) using nonlinear regression:

$$\log d = a * \exp(-b * \sqrt{t}) \qquad (2)$$

where *a* is initial discriminability at 0 s delay, *b* is the rate of forgetting, and *t* is the length of the retention interval. We were also interested in the specific effects of each disruptor on the forgetting functions, and whether initial discriminability and/or slope would be disrupted. To examine these disruptive effects, data during each disruptor were compared to the baseline data immediately prior. Paired t-tests were used to assess whether the proportion of baseline performance for parameters *a* and *b* (initial discriminability and rate of forgetting) during each disruptor were significantly different across rich and lean components.

RESULTS

Figures 2 and 3 present response rate data during the VI portion of the schedule. Figure 2 displays the average of response rates for the last 10 sessions of each successive baseline condition prior to the disruptive tests for each individual subject. Response rates in the rich condition were consistently above those in the lean condition for all subjects. Response rates were similar across successive baseline conditions. A two way (component x condition) repeated measures analysis of variance (ANOVA) confirmed these impressions, and revealed a significant effect of component, $F(1, 3) = 15.78$, $p < .001$, but not of baseline condition $F(1, 3) = 1.14$, $p = .98$, with no interaction $F(1, 3) = 0.3$, $p = .91$.

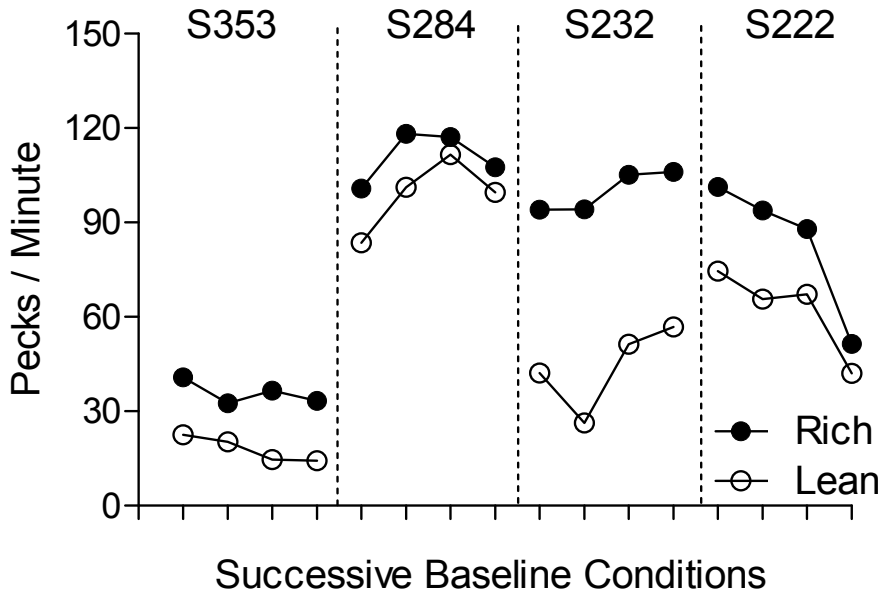

Figure 2. Average response rates for each subject for the last 10 sessions of each successive baseline condition prior to the disruptive tests.

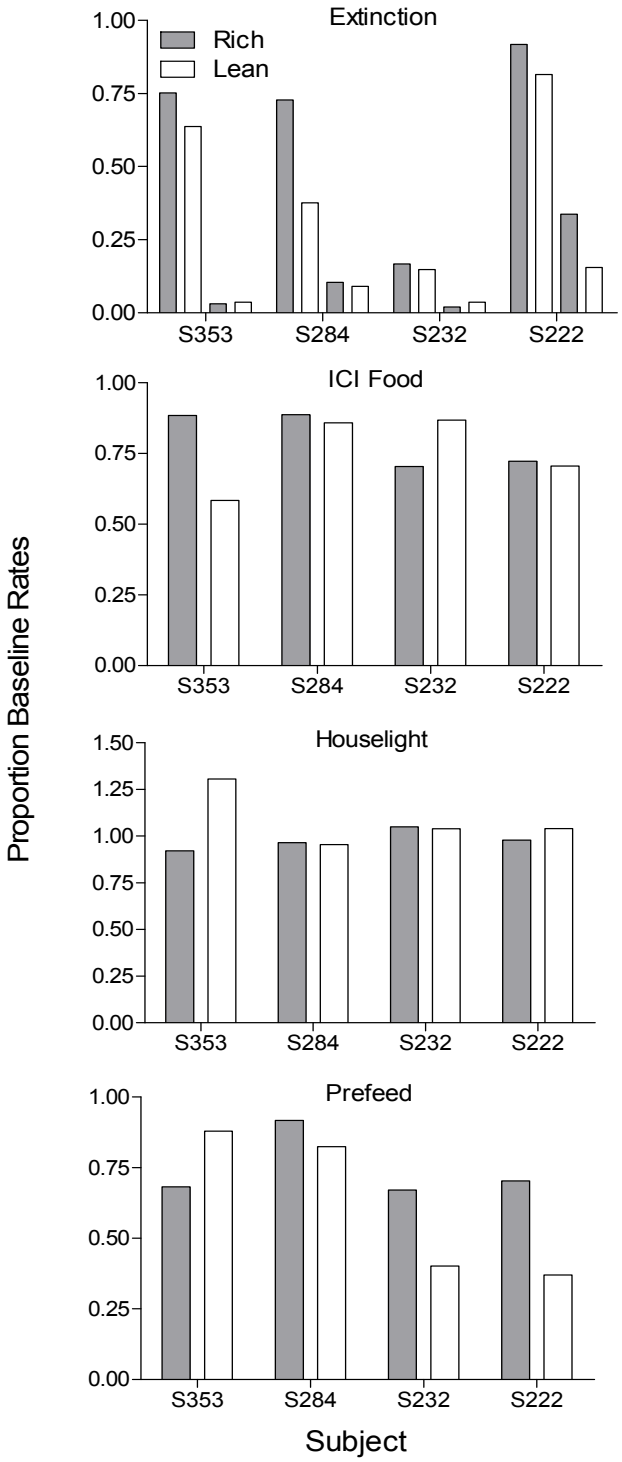

Figure 3. Proportion of baseline response rates for rich and lean components for each disruptive phase.

Figure 3 presents the proportion of baseline response rates for each subject during each disruptive test. Response rates during each disruptive test were compared to response rates during the 10 sessions of baseline immediately prior to that test. By visual inspection, extinction decreased response rates in both the rich and lean components. During the first five sessions of extinction this decrease was greater in the lean relative to the rich for each subject. A paired *t* test determined, however, that this difference was not statistically significant, $t(3) = 2.07$, $p = .13$ for the first five days, or the last five days of extinction, $t(3) = 0.923$, $p = .42$. During ICI food presentation, proportion of baseline responding also decreased for both rich and lean components, but the difference was not statistically significant; paired *t* test, $t(3) = 0.479$, $p = .66$. In the houselight presentation during the delays condition, little change was observed and the proportion of baseline response rates across rich and lean components were not significantly different, $t(3) = 1.13$, $p = .34$. During prefeeding, the proportion of baseline responding decreased in both rich and lean conditions. The decrease was greater in the lean condition than the rich condition for three out of four subjects (the exception was S353), but a paired *t* test revealed that this difference was not statistically significant, $t(3) = 1.05$, $p = .37$.

Figures 4 through 11 (each discussed and shown separately below) present data from the DMTS portion of the procedure for baseline and disruptive conditions. Figure 4 displays the forgetting functions for baseline and extinction exposure. The log *d* values were pooled over the last 10 sessions of baseline in

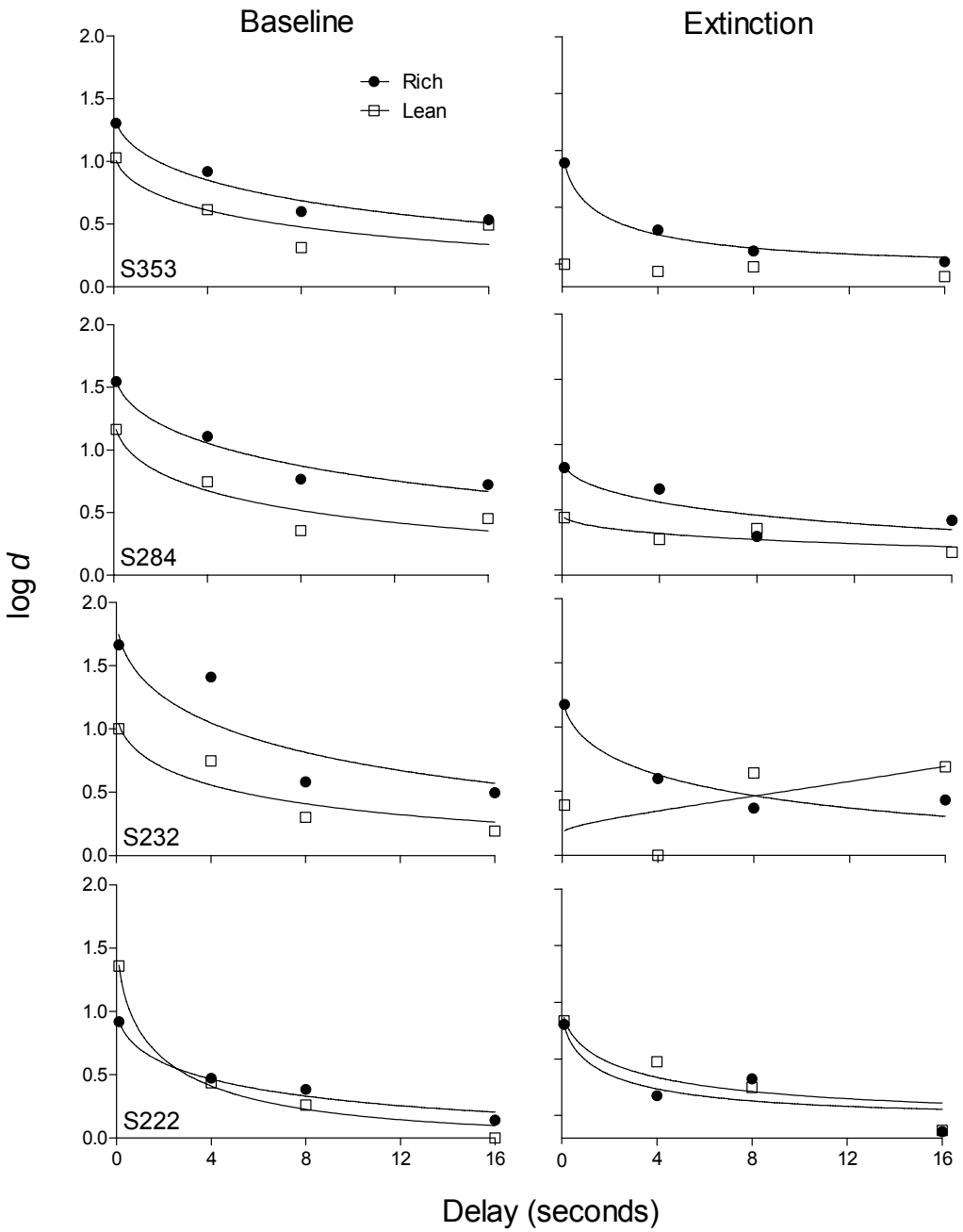

Figure 4. Forgetting functions for rich and lean components for the last 10 sessions of baseline (left column) and extinction (right column). Functions fit to the log *d* values using Equation 2.

rich and lean components separately for each subject. Log *d* values were also pooled over the 10 days of extinction in the rich and lean components separately for each subject. The curves in each panel represent the fit of the log *d* values by Equation 2. Curve fits were performed using nonlinear regression in GraphPad Prism®. Across baseline and disruptive conditions log *d* values decreased as delays increased. Accuracy decreased in rich and lean components with the introduction of extinction from baseline. Table 1 presents parameters *a* (initial discriminatbility) and *b* (rate of forgetting), and the variance accounted for (VAC) by Equation 2 for baseline and extinction, as well as all subsequent baselines and disruptive conditions (ICI food, houselight during delay, and prefeeding). Median VAC for the rich and lean components during baseline and extinction was 0.96 and 0.88, and 0.88 and 0.73, respectively.

Figure 5 displays the parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions fit by Equation 2 during extinction as a proportion of baseline performance. Parameter a (initial discrimination) decreased in both components, but the decrease was more drastic in the lean component for all subjects. The proportion of baseline performance for initial discrimination across rich and lean components was significantly different; paired *t* test, $t(3) = 3.5$, $p = .04$. Different results were found for parameter *b* (rate of forgetting). A larger *b* value signifies more rapid forgetting. For this reason the inverse of *b* (i.e., 1/*b*) was computed for the proportion baseline graphs, so that larger values indicated less disruption, which is consistent with response rate analyses (e.g., Odum et al., 2005). For

Table 1

Parameter Values for "a" (Initial Discriminability) and "b" (Rate of Forgetting) and Variance Accounted for (VAC) for Each Baseline and Disruptive Condition

	Baseline		Extinction		Baseline		ICI Food	
Subject	Rich	Lean	Rich	Lean	Rich	Lean	Rich	Lean
a								
S353	1.43	1.11	1.13	NC	1.79	1.04	1.57	1.86
S284	1.67	1.29	0.90	0.47	2.15	1.71	1.67	1.06
S232	1.92	1.17	1.30	0.17	1.93	1.13	1.14	1.79
S222	1.06	1.71	1.02	1.04	0.87	1.41	1.44	1.30
b								
S353	0.26	0.30	0.74	NC	0.31	0.46	0.23	0.36
S284	0.23	0.32	0.24	0.19	0.19	0.30	0.19	0.14
S232	0.30	0.37	0.36	-0.35	0.30	0.35	0.19	0.62
S222	0.41	0.71	0.73	0.56	0.48	0.37	0.64	0.39
VAC								
S353	0.96	0.81	0.99	NC	0.85	0.97	0.95	1.00
S284	0.96	0.90	0.75	0.73	0.80	1.00	0.75	0.79
S232	0.81	0.87	0.93	0.36	0.78	0.85	0.67	0.98
S222	0.98	0.99	0.83	0.84	0.98	0.96	0.98	0.93

	Condition							
	Baseline		HL		Baseline		Prefeed	
Subject	Rich	Lean	Rich	Lean	Rich	Lean	Rich	Lean
a								
S353	1.12	0.82	1.72	1.74	1.43	1.21	1.10	0.49
S284	1.15	1.23	1.68	1.85	2.13	1.76	1.89	1.19
S232	1.19	1.13	1.55	1.17	1.97	1.90	0.85	0.61
S222	0.95	0.94	1.18	1.11	1.48	1.11	0.47	0.48
b								
S353	0.16	0.23	0.36	0.56	0.28	0.39	0.14	0.43
S284	0.18	0.28	0.21	0.55	0.33	0.30	0.46	0.31
S232	0.18	0.37	0.31	0.35	0.21	0.43	0.18	0.44
S222	0.39	0.32	0.55	0.39	0.57	0.38	0.15	0.12
VAC								
S353	0.86	0.95	0.89	1.00	0.90	0.87	0.79	0.90
S284	0.63	0.91	0.97	0.98	0.99	0.89	0.95	0.94
S232	0.74	1.00	0.95	0.95	0.67	0.97	0.91	0.97
S222	0.87	0.86	0.99	0.95	0.99	0.89	0.78	0.95

Note. Parameter values were derived from fitting Equation 2 to the log *d* values.

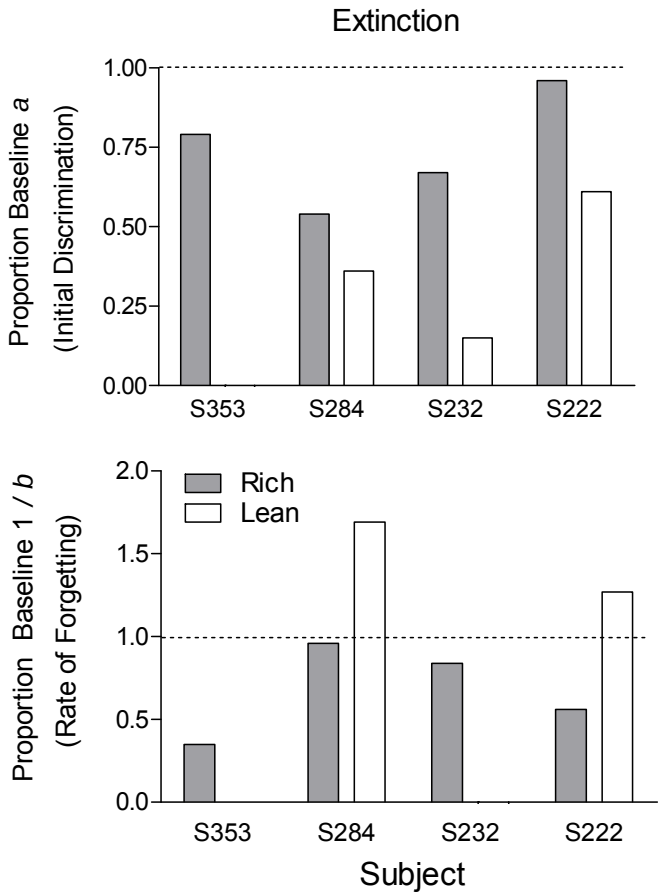

Figure 5. The proportion of baseline performance during extinction for rich and lean components for parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions (fit by Equation 2).

two subjects (S284 and S222), the rate of forgetting was disrupted less in the lean component than the rich. For the other two subjects (S353 and S232) performance in the rich component was disrupted less (values for S353 and S232 that are not displayed on the graph are below 0, or the nonlinear regression method used was unable to fit those values). As such, the proportion of baseline performance for rate of forgetting across rich and lean components was not significantly different; paired *t* test, $t(3) = 0.33$, $p = .76$.

Figure 6 displays the forgetting functions for baseline and ICI food presentation. Baseline log *d* values show a decrease in accuracy as delays increased in both the rich and lean components. Accuracy in the rich component during baseline was above the lean for three of the four subjects (with the exception of S222). During ICI food, accuracy did not always decrease, and in fact, it tended to increase in some cases at shorter delays (see S353, Figure 6 and Table 1). Median VAC (Table 1) for the rich and lean components during baseline was 0.82 and 0.97, respectively. Median VAC for rich and lean components during ICI food was 0.85 and 0.96, respectively.

Figure 7 displays parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions fit by Equation 2 during ICI food as a proportion of baseline performance. Parameter *a* (initial discrimination) decreased in some cases (e.g., S284 rich), and increased in others (e.g., S222, rich). That is, initial discrimination (parameter *a*) across rich and lean components was not systematically affected by ICI food. The proportion of baseline performance for initial discrimination across rich and lean components was not significantly different; paired *t* test, $t(3) = 0.91$, $p = .39$. The proportion of baseline performance for *b* (rate of forgetting) was not systematically affected by ICI food presentation. For two subjects (S284 and S222), the rate of forgetting was disrupted less in the lean component than the rich, while the other two subjects (S353 and S232) were disrupted less in the rich than lean. These differences, however, were minimal in some cases. The proportion of baseline performance for rate of forgetting across rich and lean

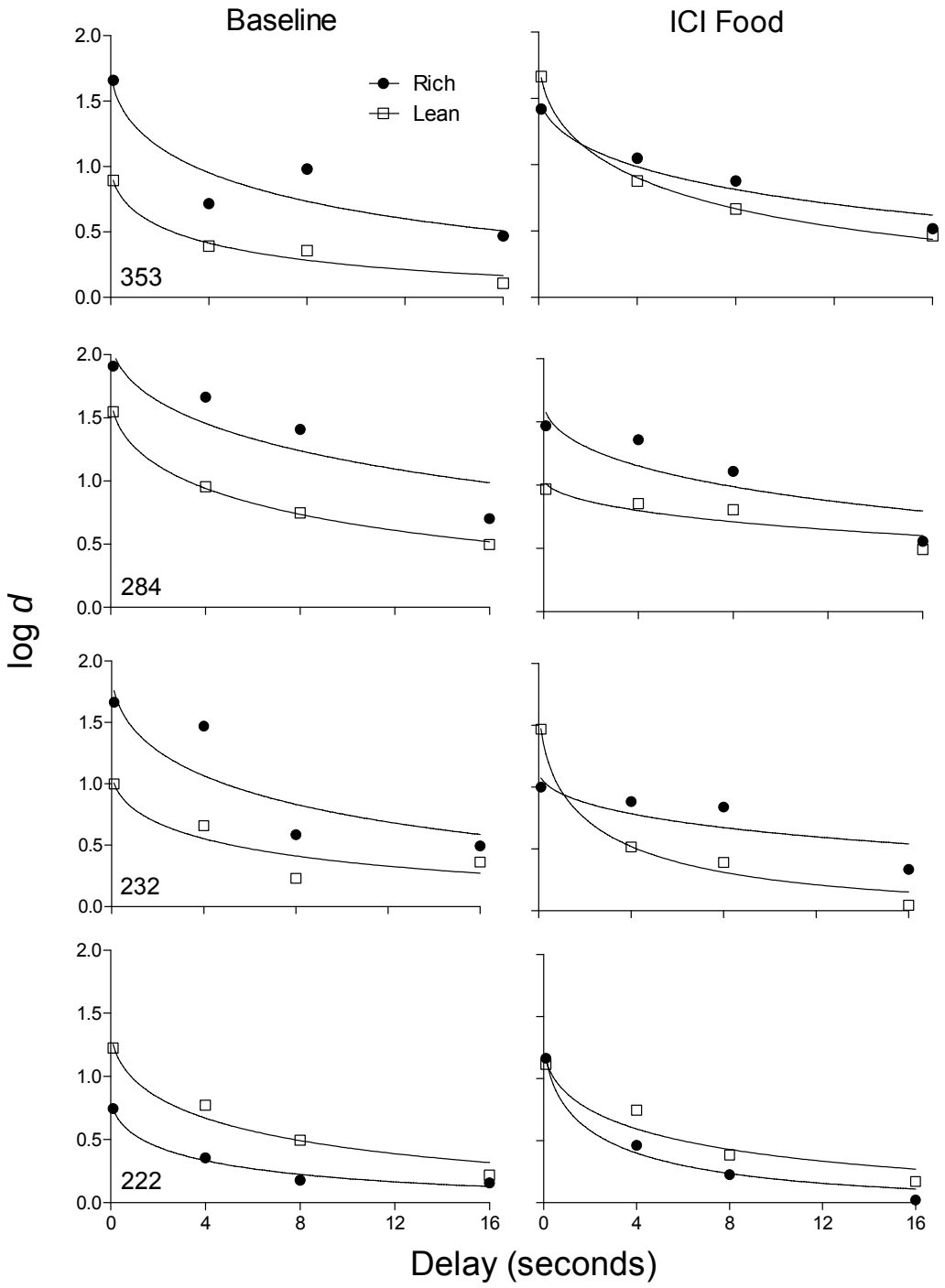

Figure 6. Forgetting functions for rich and lean components for the last 10 sessions of baseline (left column) and ICI food (right column). Functions fit to the log *d* values using Equation 2.

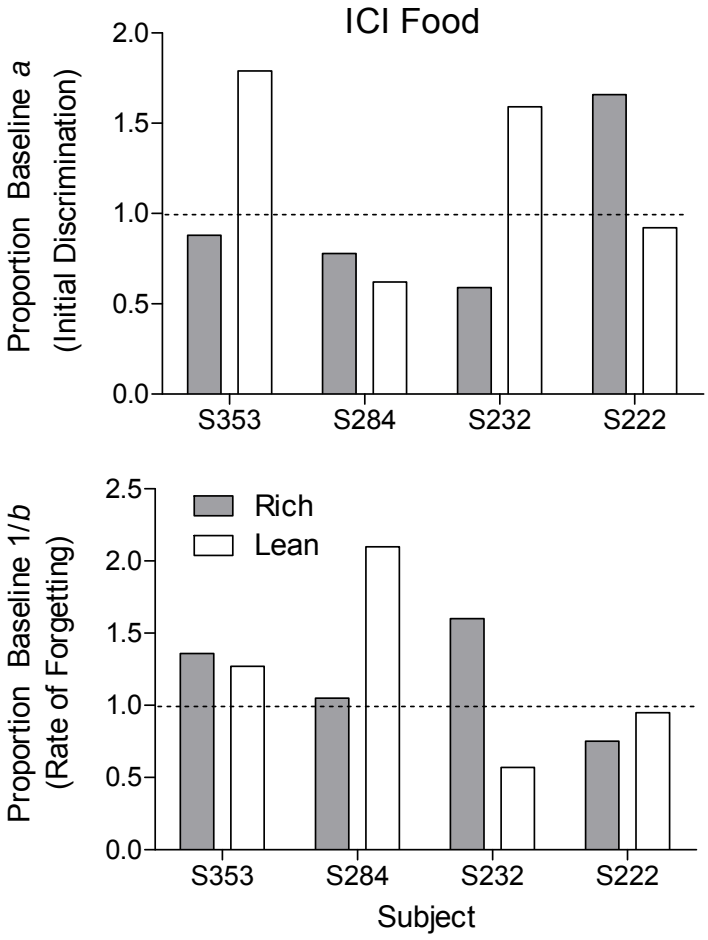

Figure 7. The proportion of baseline performance during ICI food for rich and lean components for parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions (fit by Equation 2).

components was not significantly different; paired *t* test, $t(3) = 0.11$, $p = .91$.

Figure 8 displays the forgetting functions for baseline and the lit houselight during the delays. Baseline log *d* values show a decrease in accuracy as delays increased in both the rich and lean components. During baseline, accuracy in the rich component was above the lean for three of the four subjects (with the exception of S222). During the disruptive phase, in which the houselight was lit

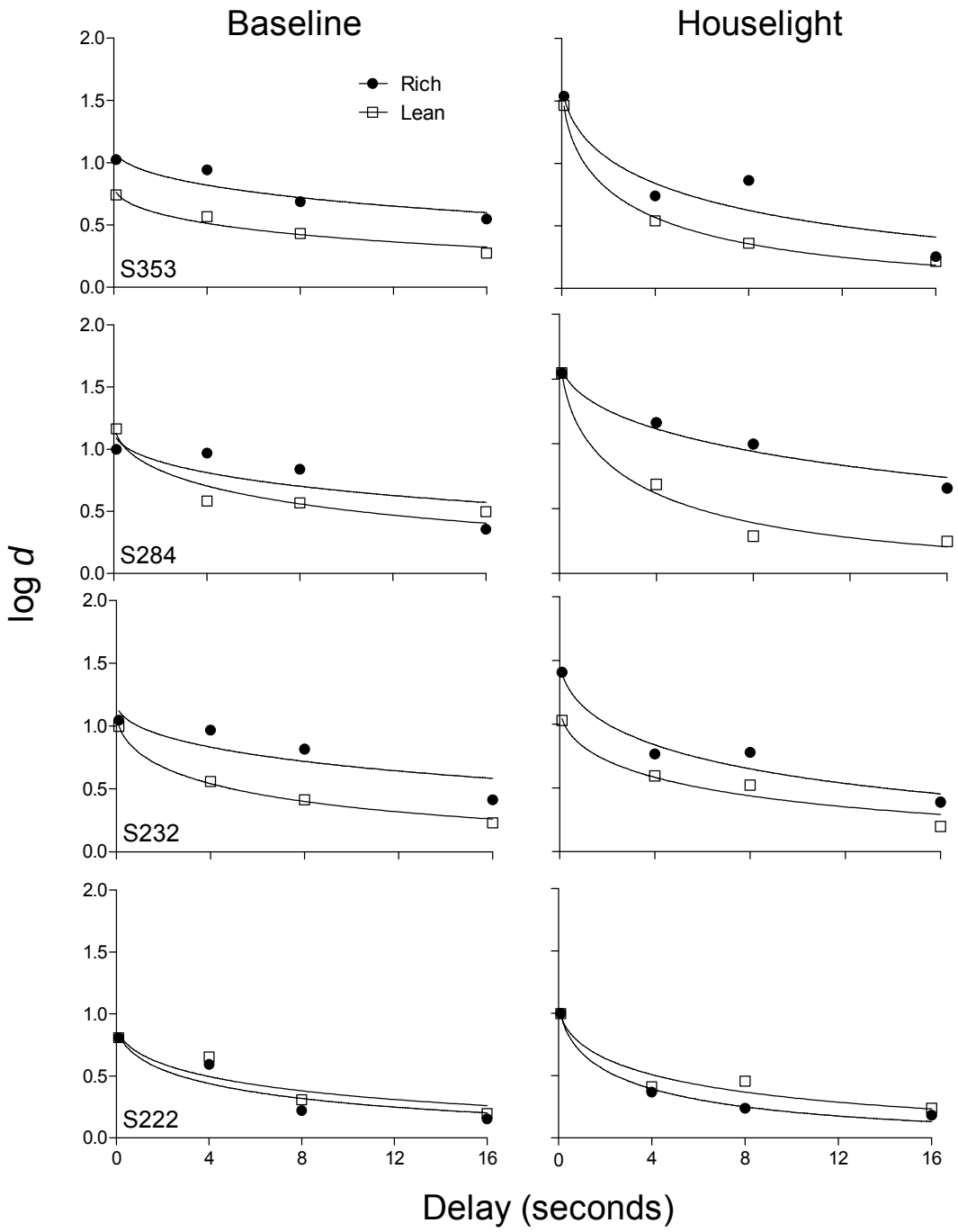

Figure 8. Forgetting functions for rich and lean components for the last 10 sessions of baseline (left column) and the lit houselight during the delay (right column). Functions fit to the log *d* values using Equation 2.

during the delays, initial accuracy generally increased across rich and lean conditions, and accuracy in the rich condition remained above the lean condition. Although lighting the houselight during the delays enhanced performance to some degree (at least initial accuracy), this may in part be due to the low levels of baseline accuracy compared to previous baselines for three of the four subjects (S222 was the exception). Additionally, the houselight presented during the shortest delay (0.1 s) would likely have a minimal effect, compared to the longer delays (e.g., Brown & White, 2011). Median VAC for the rich and lean components during baseline was 0.80 and 0.93, respectively. Median VAC for rich and lean components during the disruptive houselight phase was 0.96 and 0.97, respectively.

Figure 9 displays parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions fit by Equation 2, in which the houselight was lit during the delays as a proportion of baseline performance. Parameter *a* (initial discrimination) increased in some cases in both the rich and lean components. The increase in proportion of baseline performance was greater in the rich component for Subject 232, greater in the lean for Subject 353, and almost no differences were observed between rich and lean for Subjects 284 and 222. The proportion of baseline performance for initial discrimination across rich and lean components was not significantly different; paired *t* test, $t(3) = 0.63$, $p = .55$. For the proportion of baseline performance for *b* (rate of forgetting), however, all subjects showed a decrease from initial baseline performance. The differences

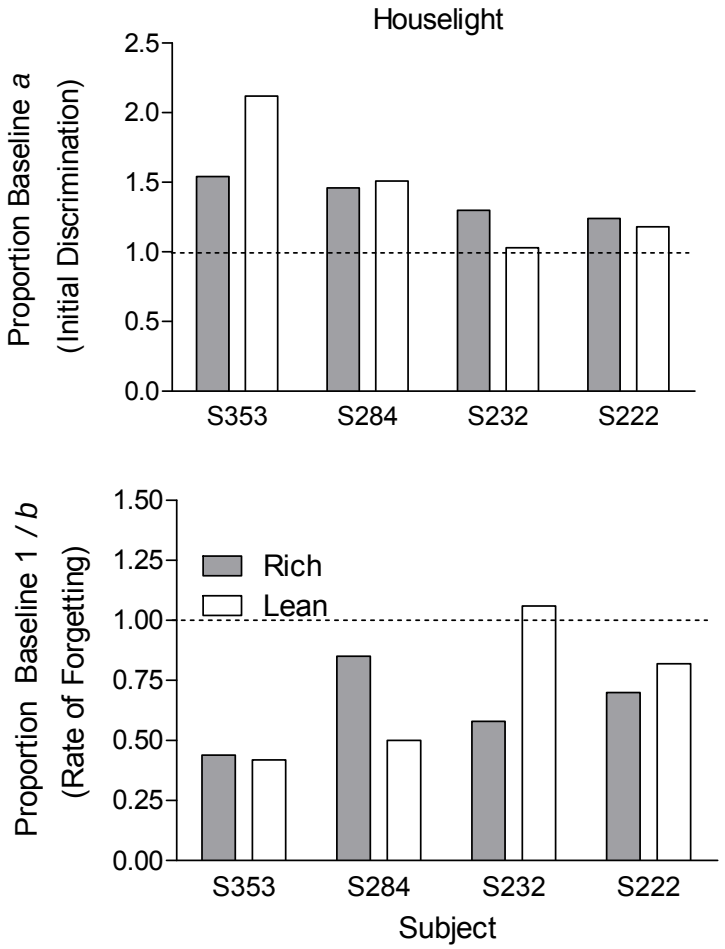

Figure 9. The proportion of baseline performance during houselight disruption for rich and lean components for parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions (fit by Equation 2).

from baseline were not systematic across rich and lean components. For example, Subject 284 showed less disruption in the rich component, while Subject, 232 showed less disruption in the lean component. The proportion of baseline performance for rate of forgetting across rich and lean components was not significantly different; paired *t* test, $t(3) = 0.51$, $p = .63$.

Figure 10 displays the forgetting functions for baseline and prefeeding.

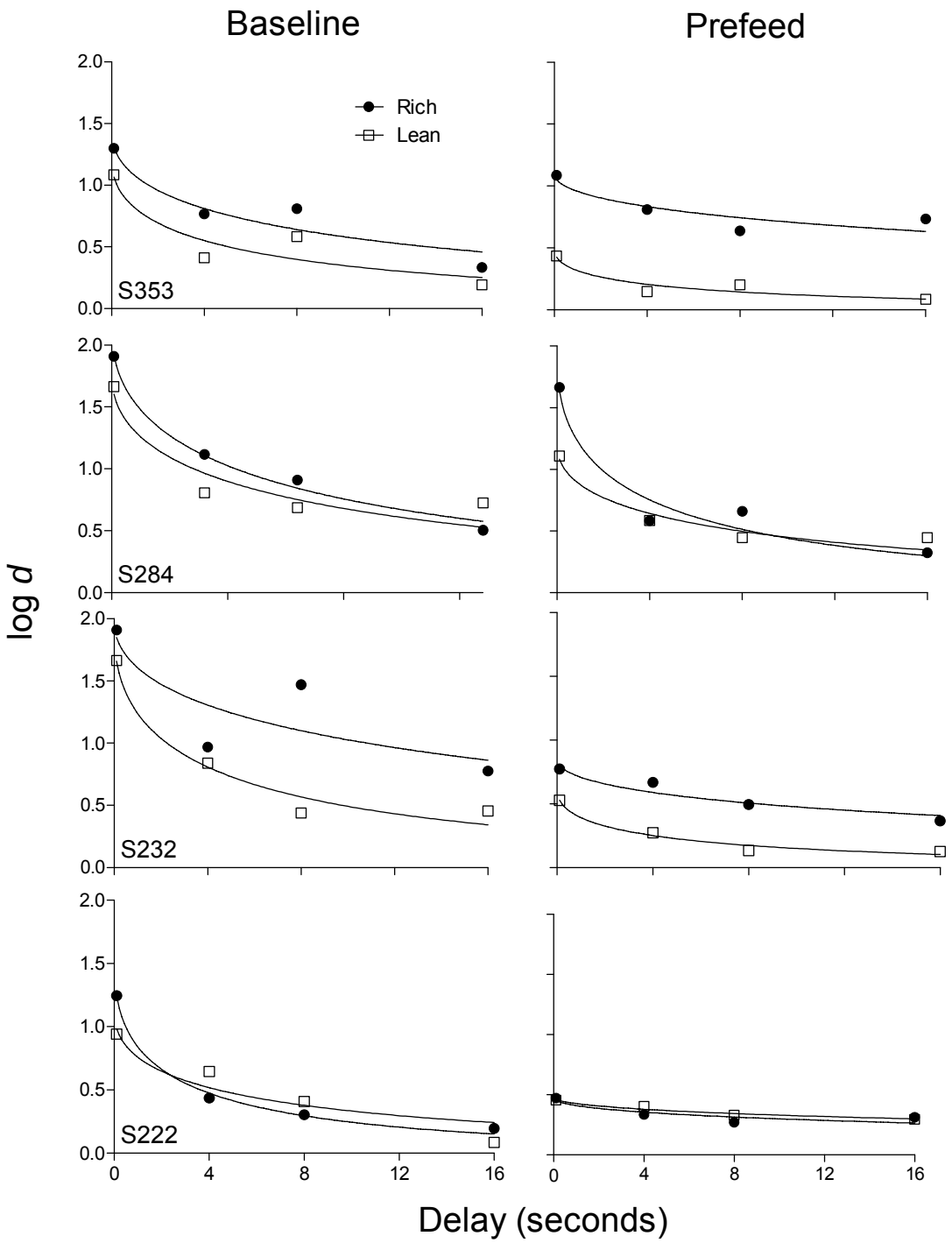

Figure 10. Forgetting functions for rich and lean components for the last 10 sessions of baseline (left column) and prefeeding (right column). Functions fit to the log *d* values using Equation 2.

Baseline log *d* values show a decrease in accuracy as delays increased in both the rich and lean components. During baseline, accuracy in the rich component was above the lean for three of the four subjects (with the exception of S222). During prefeeding, accuracy decreased across rich and lean conditions, although accuracy in the rich condition remained above accuracy in the lean. Median VAC for the rich and lean components during baseline was 0.95 and 0.89, respectively. Median VAC for rich and lean components during prefeeding was 0.85 and 0.95, respectively.

Figure 11 displays the parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions fit by Equation 2 during prefeeding as a proportion of baseline performance. Parameter *a* (initial discrimination) decreased in both the rich and lean components, but the decrease was more drastic in the lean for three of the four subjects (S222 was the exception). The proportion of baseline performance for initial discrimination across rich and lean components, however, was not significantly different; paired *t* test, $t(3) = 1.44$, $p = .25$. The proportion of baseline performance for *b* (rate of forgetting) was not systematically affected by prefeeding. For two subjects (S353 and S222), the rate of forgetting was disrupted less in the rich component than the lean. For the other two subjects (S284 and S232) differences between the proportion baseline of rich and lean components were minimal. The proportion of baseline performance for rate of forgetting across rich and lean components was not significantly different; paired *t* test, $t(3) = 1.42$, $p = .25$.

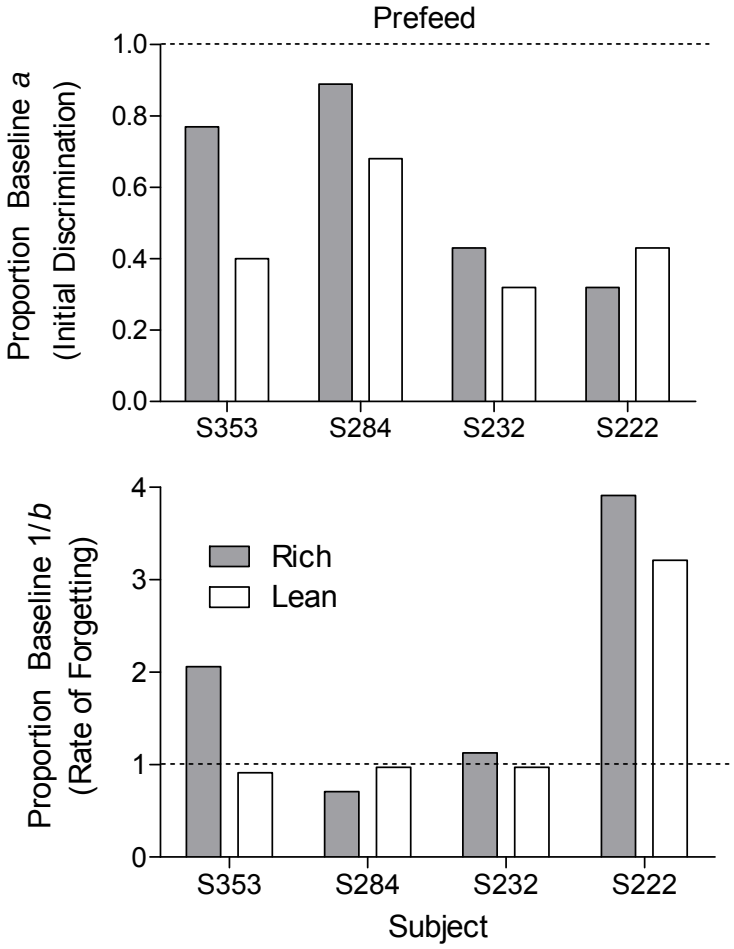

Figure 11. The proportion of baseline performance during prefeeding for rich and lean components for parameters *a* (top panel) and *b* (bottom panel) of the forgetting functions (fit by Equation 2).

DISCUSSION

Several findings emerged from the present study, in which we explored disruption of response rates and forgetting functions using magnitude to establish rich (4.5-s access to food) and lean (0.75-s access to food) contexts within a VI-DMTS procedure. First, response rates during successive baseline conditions were consistently higher in the rich component relative to the lean. No significant differences between response rates in the rich component relative to the lean, however, were found during disruptive conditions.

Second, accuracy in the rich component was consistently above lean during baseline conditions. Third, when accuracy data from the rich and lean components were compared across disruptors (extinction, ICI food, houselight during delay, prefeeding) initial discriminability (parameter *a*) in the rich component was less disrupted than the lean during extinction. No other significant differences were found between rich and lean components for the other disruptors. Each of these findings will be discussed in turn.

Response rates were higher in the rich component than the lean during successive baseline conditions. These results extend those of Odum and colleagues (2005), in which differing probabilities were used to establish rich and lean contexts in a VI-DMTS procedure. Differing magnitudes (used in the present study) and differing probabilities (used in Odum et al., 2005), therefore, have similar effects on response rates across rich and lean components.

When the effects of each disruptor (extinction, ICI food, houselight during

delay, and prefeeding) on response rates were examined, however, no significant differences were found between rich and lean components. This finding is at odds with previous research on response rates across rich and lean components using a VI-DMTS procedure (e.g., Nevin et al., 2003; Odum et al., 2005). Contrary to the present experiment, in which differing magnitudes were used to establish rich and lean contexts, differing probabilities were used in Odum and colleagues, as well as Nevin and colleagues. As previously noted, stronger effects in biasing responding have been reported with frequency of the reinforcer than with magnitude (Boldero et al., 1985). When magnitude is used to establish rich and lean contexts, therefore, it is possible that response rates across rich and lean components during disruption are affected similarly. Alternatively, using probabilities to establish rich and lean contexts renders response rates in the rich component less susceptible to disruption (or response rates in the lean more susceptible).

Parameters *a* (initial discriminability) and *b* (rate of forgetting) of the forgetting functions were affected differently by each disruptor. Replicating the results of Odum and colleagues (2005), parameter *a* was decreased significantly during extinction, but *b* was not. A similar result was found for prefeeding in the present study. That is, parameter *a* decreased during prefeeding for three of the four subjects (although these differences were not statistically significant across rich and lean components), but there was no clear effect on parameter *b*. Odum and colleagues found that during prefeeding, when pigeons were fed 20 grams

performance was not disrupted, but with 40 grams they ceased responding altogether. In the current study, we fed pigeons an intermediate amount of 30 grams of food during prefeeding and found that performance was disrupted, but not so severely that the subjects would not respond.

Extinction and prefeeding both affected parameter *a* (initial discriminability) but not *b* (rate of forgetting). These data suggest that extinction and prefeeding affect encoding of the sample (possibly through attention), but have little effect on remembering. As suggested by Odum and colleagues (2005), the reason extinction decreased initial discriminability may be because attention to the samples was decreased.

Nevin and colleagues (2007) extended this concept to suggest that extinction (or other disruptors) could decrease not only attending to the sample stimuli, but also to the comparison stimuli. Similarly, by prefeeding subjects before each session, the motivation to attend to sample and/or comparison stimuli was likely decreased. This theory helps to describe the overall form of the functions, but deciphering the precise differences in attention that result from using probabilities versus magnitudes may be difficult within the present study.

During ICI food, no significant differences between initial discriminability or rate of forgetting were found between rich and lean components. In the research of Odum and colleagues (2005), however, ICI food did increase the rate of forgetting. The lack of change in accuracy during ICI food may be related to the subjects' extensive experience with the DMTS task.

When the houselight was lit during delays, no significant differences in initial discriminability or rate of forgetting were found between rich and lean components. This may, in part, be due to the increase in rate of forgetting resulting from the increase in initial accuracy, rather than a decrease in accuracy at longer delays. Because there was little change in accuracy at longer delays in either the rich or lean components, it is not surprising that no difference in persistence between the two components was found. One potential reason initial accuracy increased during the presentation of the houselight during delays could be related to the level of initial accuracy during the baseline immediately prior. Initial accuracy in the third baseline condition (see Figure 8) was low when compared to other baseline conditions. This may have allowed more opportunity than usual for an increase. Because experienced birds were used in this experiment, it is also possible that the houselight was somehow associated with reinforcement in their learning histories. Additionally, these subjects were exposed to a variation of this baseline for over a year before disruptors were presented. Due to their extensive experience with the task, it is possible that lighting the houselight had no distracting effects in either the rich or lean components.

Although there are some differences between the present results and previous findings, these data generally agree with the theory of remembering proposed by Nevin and colleagues (2007). As discussed previously, relatively more reinforcement could lead to increases in attention to the sample and

comparison stimuli and potentially result in higher accuracy. Although this model specifically addressed the influence of reinforcement probability on attention, and the present experiment employed reinforcement magnitude, the general form of the forgetting functions were still similar. For example, as generally predicted by Nevin and colleagues, baseline accuracy in the rich component was above accuracy in the lean component (see Figures 4, 6, 8, and 10). When DMTS performance was disrupted, forgetting functions in the rich condition still remained above the lean in most cases (Figure 4, 6, 8, and 10). Additionally, accuracy was more persistent in the rich component than the lean during extinction. Although not statistically significant, the same trend was observed for three of the four subjects during prefeeding. Systematic differences in accuracy between rich and lean components during the other disruptors were not observed.

When systematic differences in accuracy between rich and lean components were found in the present study, accuracy in the rich component was more persistent than in the lean. On the other hand, Nevin and Grosch (1990) found a lack of systematic differences in accuracy across rich and lean components during disruption in a signaled DMTS task. The procedure used in the present study (VI DMTS), however, was different than that used in Nevin and Grosch.

The differences found in persistence of DMTS performance upon disruption across these experiments may be due to trial structure (Nevin et al.,

2011). In the present experiment, we employed a VI DMTS procedure, in which a multiple schedule leads to DMTS trials in each component. Within each rich or lean component, four trials were presented each time (thus rich and lean trial presentations were not random). In the task used by Nevin and Grosch (1990), an auditory stimulus signaled rich and lean trials, which were randomly presented. Nevin and colleagues (2011) proposed these and other differences in overall trial structure could affect attention to the sample and comparison stimuli, and thus lead to greater persistence in the rich component in a VI DMTS procedure. The opposite effect in a signaled DMTS procedure is predicted (more persistence of accuracy in the lean component upon disruption). For these reasons, it is likely that trial structure was more influential in the divergent findings of Nevin and Grosch, rather than the use of magnitude of reinforcement to establish rich and lean contexts.

While the present experiment extended previous findings on the effects of disruption on response rates and accuracy within a VI DMTS procedure, there are some limitations. One limitation was the number of subjects used. With the use of only four subjects, significant differences between rich and lean components may fail to be detected, despite moderate effect sizes. To address this issue, we are currently conducting the same experiment with four additional subjects.

We used magnitude to establish rich and lean contexts within a VI DMTS procedure in the present experiment. Although we differed magnitude by differing

the length of hopper presentation as in previous studies (e.g., Nevin & Grosch, 1990; Brown & White, 2009), this method is dependent on the amount of time it takes the subject to gain access to the hopper, which may be different from trial to trial. This lack of precision in the current method may help to explain the differences found between performance in VI DMTS procedures where probability is used to establish rich and lean contexts, rather than magnitude. Perhaps a more precise method would be to alter the number of pellets delivered (e.g., 1 versus 5). Future experiments could address this issue by using the same VI DMTS procedures, but altering the way in which magnitude is differentiated.

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