The Behavior Analyst Today

VOLUME 14
NUMBERS 1 & 2
JULY 2014

IncChains: a program written in Visual Basic® 2010 for studying variables affecting human learning

Noah S. Dermer[1], Marshall Lev Dermer[2], & David M. Trejo[2]

ABSTRACT

At the level of the single-subject, an intervention's effects on learning can be assessed by the repeated acquisition of chains. In this procedure, during a session, a participant can repeatedly enter a sequence of *k* responses (the chain). Whenever the chain is completed sans error, reinforcement occurs. From session to session the chain changes so that each sequence is novel but approximately equivalent. An intervention's effects are assessed be manipulating the intervention's presence/absence and examining, for example, the length of the longest chain completed. This often-used procedure's major drawback is that during a session a chain cannot be lengthened. This drawback is addressed by incremental procedures including IncChains: software for Microsoft Windows® , designed for human participants.

KEYWORDS: chains, incremental, repeated acquisition, single-subject, learning, memory, human

Although most psychologists seek to understand or apply findings to individual organisms, most psychological researchers aggregate data across organisms. This misalignment between goals and methods can be reduced by using single-participant designs and methods (Dermer & Hoch, 1999). One particularly useful method for studying the effects of interventions on learning has been the repeated acquisition of chains (RA).

First described by Boren and Devine (1968) and reviewed by Cohn and Paule (1995), the RA procedure permits an organism to access reinforcement after it has completed a chain of K responses. The chain remains constant for *each session* but *changes from session to session* so that the chains are novel but approximately equivalent. When a steady-state strategy is used (Baron & Perone, 1998), sessions are continued until a learning measure, such as the proportion of incorrect responses, does not considerably change from session to session. Once such a steady state is established, the intervention is introduced and the sessions continue until a second steady state is achieved. This second steady state permits assessing the intervention's effect relative to the first steady state in terms of the learning measure.

RA procedures have been primarily used in pharmacological and toxicological research with non-human (e.g., Cohn & Paule, 1995; Galizio, McKinney, Cerutti, & Pitts, 2009) and human organisms (e.g., Bickel, Higgins, & Griffiths, 1989; Fischman, 1978; Kelly, Hienz, Zarcone, Wurster, & Brady, 2005; Makris, Rush, Frederich, Taylor, & Kelly 2007). RA procedures have also been used to explore the effects of aging on human learning (Perone & Baron, 1982). Indeed, Perone and Baron's work served as a model for developing RA software that runs in a MS-DOS environment (Dermer & Dermer, 2000). However, a problem with RA procedures is that researchers must specify the chain's length before each session. If this length is too short or too long then the RA procedure may be insensitive.

Chain length is addressed by the incremental repeated acquisition procedure (IRA) which permits lengthening a chain within sessions. For example, on the key board's number pad, the initial chain may require one response such as pressing the 1 key. If this one response is repeated to some criterion, the advancement criterion, then the organism accesses reinforcement and the chain is lengthened by one response, for example, pressing the 3 key. The procedure is now repeated with the two-response chain, pressing the 3 key and next pressing the 1 key. When this chain is repeated to criterion, the chain is again incremented by one response, for example, pressing the 2 key. Worth noting is that in such a "backward chaining procedure" the new response (here pressing the 2 key) is added to the already established chain (here pressing the 3 key and next pressing the 1 key; Cohn & Paule, 1995; Weinberger & Killam, 1978).

Like RA procedures, IRA procedures are primarily used in pharmacological and toxicological research (e.g., Bailey, Johnson, & Newland, 2010; Rodriguez, Morris, Hotchkiss, Doerge, Allen, Mattison, & Paule, 2010; Wright & Paule, 2007; Wright et al., 2007). Several studies with humans, however, have used IRA procedures for other purposes. For example, IRA procedures have been used to explore the learning of children with and without disabilities (Paule, Cranmer, Wilkins, Stern, & Hoffman, 1988) and of varying IQ, age, or sex (Baldwin, Chelonis, Prunty, & Paule, 2012; Paule,

1 Madison, Wisconsin, 2 University of Wisconsin—Milwaukee

Author note: Special thanks to Alan Baron and Michael Perone for introducing MLD to this procedure and to Jay Moore for helping us design the software.

Author contact information: Marshall Lev Dermer, Garland Hall, Department of Psychology, University of Wisconsin—Milwaukee, P.O. Box 413, Milwaukee, WI 53201, Tel: (414) 533-2800, email: dermer@uwm.edu

Chelonis, Buffalo, Blake, & Casey, 1999). Also, IRA procedures have been used to explore the learning of adults diagnosed with mental retardation as function of the value of the activity that presumably reinforced completing chains (Zayac & Johnson, 2008) and the learning of adults diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) as a function of whether they were on or off stimulant medication (Trejo, 2011).

Besides studying the learning or "acquisition" of new chains, researchers have studied behavior with an established chain (Higgins et al., 1992; Perone & Baron, 1982; Thompson & Moerschbaecher, 1979). In such a "performance" condition, the chain remains constant from session to session. Of course when such a condition is conjoined with the IRA procedure, even for the performance chain the newest responses must be "discovered" and so will not be as well established as are older responses.

A single session can be divided into multiple pairs of acquisition and performance components. These performance components can provide "control data" which can rule out changes during acquisition components attributable to non-specific factors such as motivation, alertness, or motor control (see Cohn & Paule, 1995, p. 398–399).

Here we introduce a program written in Microsoft Visual Basic® 2010, for studying variables affecting human learning using the IRA procedure on a computer running contemporary Microsoft Windows® operating systems such as XP, Vista, and Windows 8. IncChains does not require special hardware unlike other methods (e.g., Baldwin et al., 2012) and it implements acquisition and performance components (cf., Zayac & Johnson, 2008).

The program permits conducting a session in which performance and acquisition components alternate multiple times. Because responding during the performance component is usually of less interest than responding during the first acquisition component, a session always begins with a performance component. In this way, activities during the first acquisition component are buffered from activities that occurred before the session.

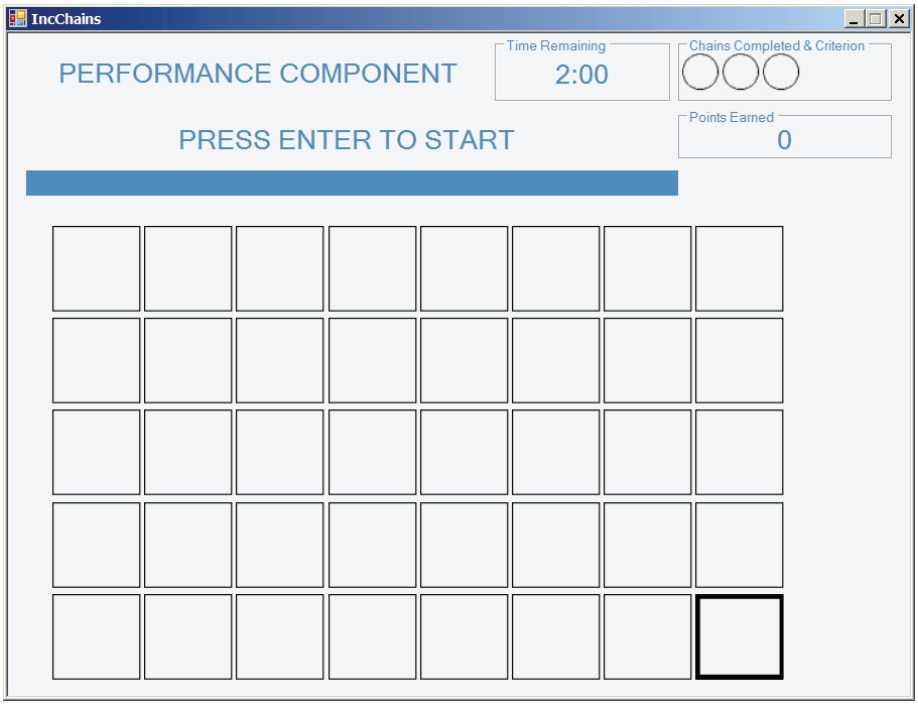

Figure 1. Initial IncChains window for the performance component showing: two minutes remain for depressing keys, the criterion for incrementing a chain is completing three chains without errors, no chains have been completed without errors, no points have been earned, the prompt "PRESS ENTER TO START" is present, the longest possible chain is 40 responses, and a frame (the position marker) surrounds the square that corresponds to the current response.

» A NON-TECHNICAL OVERVIEW OF INCCHAINS' IRA PROCEDURE

The easiest way to understand the procedure, is to review the introductory instructions we have provided participants.

This software tests your ability to learn new sequences of key presses as well as to recall previously learned sequences. You are to press keys as quickly and with as few errors as possible, so as to correctly enter longer and longer sequences of key presses. The longer the sequences you enter, the more points you earn. Of course, we cannot tell you which keys to press other than you can choose from the 1, 2, and 3 keys.

Let me now outline what you will be doing and later you can practice using the software. You will notice that the computer screen contains 40 grey squares [see Figure 1]. Each square corresponds to either a 1, 2 or 3 key on the keypad. There are 40 squares because you may be able to eventually depress a sequence that is 40 keys long. Of course, most people cannot remember 40 key positions. So we start with one key and if you discover and press that key three times then you earn one point and you can start working on a two-key sequence. When you complete the two-key sequence, three times without errors you earn two points. Then you can work on a three-key sequence and when you complete the three-key sequence, three times without errors you earn three points, etc. In this way, you can come to discover and press more and more keys to enter longer and longer sequences and earn more and more points.

Look at the computer screen. The black frame, the position marker, around the lower-right square indicates that you must discover the key that matches that square. If the frame were around the square just to the left, this would indicate that you must discover and depress the key that matches that square.

The computer provides various kinds of feedback. The basic idea is this. If you press a correct key then the corresponding square will turn green and you will hear a high-pitched "click." If you press the wrong key then the square will remain grey and you will hear a low-pitched "click." When you complete a sequence of key presses without error you will hear a "chirp." When you complete a sequence three times, without errors, you

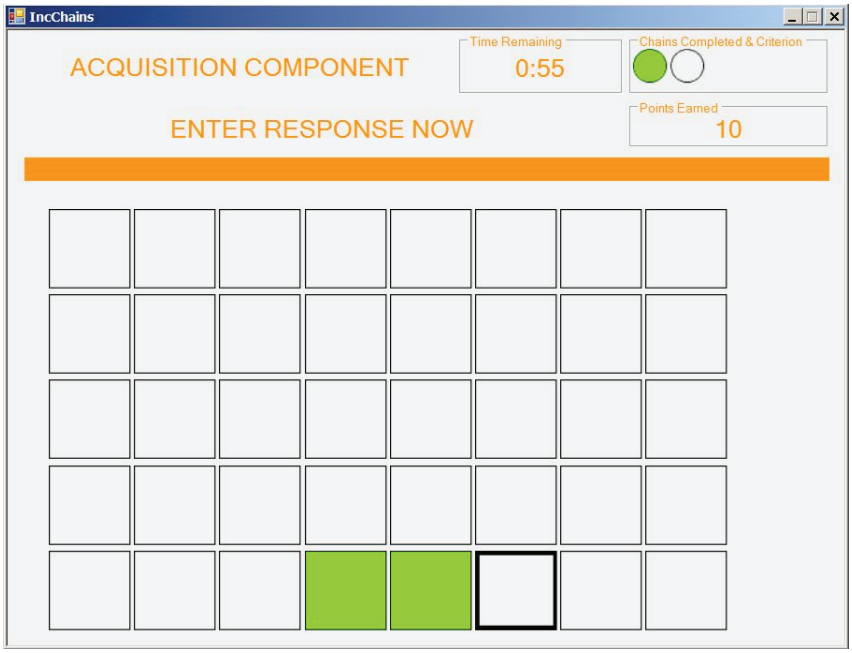

Figure 2. IncChains Window for the acquisition component showing: that 55 s remain for depressing keys , the criterion for incrementing a chain is completing two chains without error, one chain has been completed without error since the participant began working on a five-response chain, ten points have been earned so far in the session, the longest possible chain is 40 responses, and a frame (the position marker) surrounds the square that corresponds to the current response.

will hear a pinball-machine sound, you will earn points, and the black frame will shift one square left so you can work on a longer sequence and earn points. Remember your job is to press keys in the right order as quickly as possible and with as few errors as possible so as to enter increasingly long sequences. The points, amount of time left in a component, and number of sequences completed correctly are displayed in windows, at the upper right of the screen.

At this point, we ask participants to use IncChains. Figure 2 provides more details including the window for a participant who: is working on a five-response chain, has correctly once entered this chain, and has correctly entered the two newest responses.

» ILLUSTRATION

Trejo's research (2011) illustrates using IncChains with an alternating treatments design. Participants were adults diagnosed with ADHD who reportedly benefited greatly from short-acting stimulant medication as confirmed by their psychiatrists. In the experiment's main phase, participants came to the laboratory for 30, early-morning sessions. Some 90 min before each session, participants had been instructed to administer an opaque capsule that contained either medication or sucrose. The capsules had been arranged so that for blocks of two-sessions one of each kind of capsule was randomly ordered. This arrangement produced an alternating treatments design.

Participants worked in a quiet room with IncChains. It had been programed so that a session included one performance component and one acquisition component, chains could be up to 40 responses long, the criterion for adding a new response was having completed three chains sans error , and component duration (the time available for depressing numeric keys) was 5 min. Worth noting is that actual component duration was longer, about 10 min, because of the time required for other activities.

Trejo (2011) explored various measures. Below, for one participant are results for three measures: the longest chain completed to criterion, the rate of correct key presses per minute, and the rate of incorrect key presses per minute.

The length of the longest chains completed to criterion

Consider the length of the longest chain errorlessly completed thrice. Their lengths are presented in Figure 3 as a function of sessions, performance versus acquisition components, and medication versus placebo conditions.

Clearly, the chains were longer during the performance component than they were during the acquisition component. Also, during the performance component (but not so markedly during the acquisition component) chain length systematically increased with sessions. If medication enhanced learning, then the chains should have been longer with the medication than with the placebo. Such a pattern is only suggested by the data for the last four sessions of each acquisition condition. This pattern is also evident for the performance data. Although medication did not appear to reliably increase chain length throughout the experiment, the data do appear orderly.

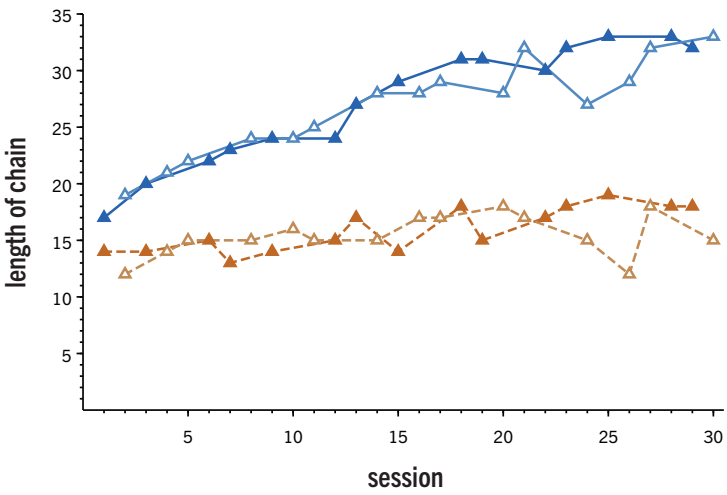

Figure 3. The length of the longest chain completed to criterion as a function of: sessions, performance (solid line) versus acquisition component (dashed line), and medication (filled triangle) versus placebo (open triangle) conditions.

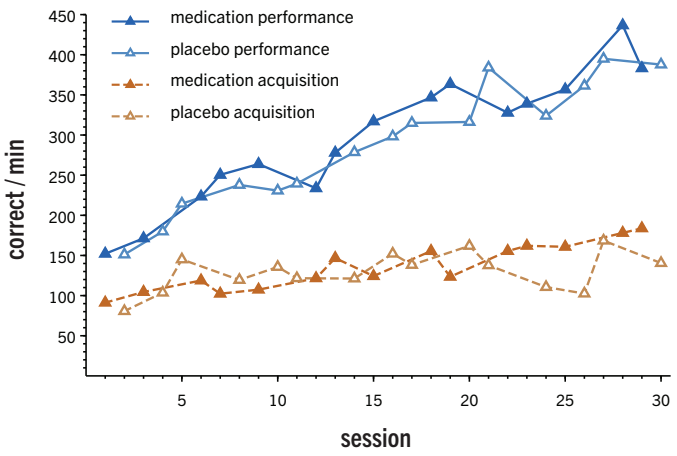

Figure 4. Correct key presses per minute as a function of: sessions, performance (solid line) versus acquisition component (dashed line), and medication (filled triangle) versus placebo (open triangle) conditions.

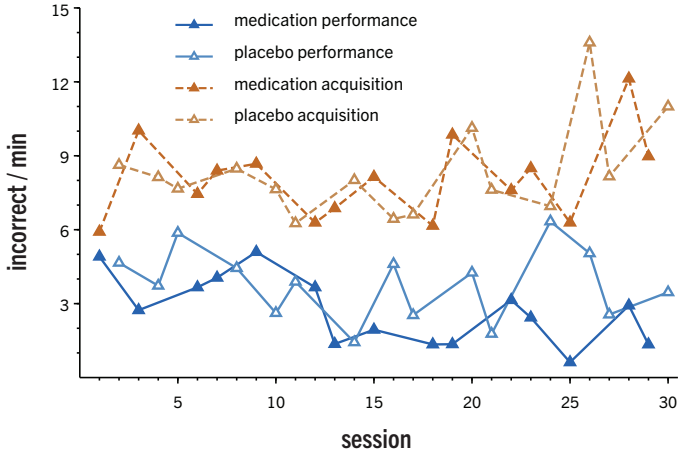

Figure 5. Incorrect key presses per minute as a function of: sessions, performance (solid line) versus acquisition component (dashed line), and medication (filled triangle) versus placebo (open triangle) conditions. Note the scale change from Figure 4.

Rates of key presses

For each component the rate of correct key presses was the total number of correct key presses, beginning with a chain of length one and ending with the longest chains completed to criterion, divided by the number of seconds available for entering such responses. Worth noting, is that in this illustration these rates were calculated only for chains completed to the criterion (thrice). As a result of omitting incomplete chains the denominator, above, was shorter than the programmed component duration which was 5 min for this illustration. Rates of corrects are presented in Figure 4 which reveals a pattern much like that for the length of the longest chain completed.

Analogously calculated to the rates of correct presses were the rates of incorrect presses. Because these rates were quite low, Figure 5 presents them on a scale which ranges only from 0 to 16 responses. Of course, rates of incorrects were higher during the acquisition component than they were during the performance component. For the performance component, consider the last four sessions of the medication and the placebo conditions: with medication rates of incorrects appear to be lower than with the placebo. Worth noting is that the rates in Figure 5 appear much more variable than those in Figure 4 due to the different scales. When the rates of incorrects are plotted on the same scale as the rates of corrects then the rates of incorrects for all conditions appear at the bottom of the graph with no medication effects at all suggested.

Why was Trejo's procedure insensitive to whether medication was in effect for this participant (and two others)? Trejo suggested that the sessions may have been too few and too short. Perhaps the sessions were only "challenging" towards the end of the 30 sessions. It may, however, be impractical to schedule more sessions with a human participants even when they each earn $300 for completing the sessions as they were paid by Trejo. A more effective strategy may be to schedule more components for each session so that a session would last for 35 or 40 min and participants would be challenged quite early in a series of such sessions.

» IMPLICATIONS AND ACCESSING INCCHAINS

Although many researchers have explored treating ADHD with stimulant medication, they appear most often to have used group designs that focus on well-learned responses (Trejo, 2011). Even practitioners providing services to individual clients with ADHD likely assess well-learned responses, such as time-on-task, rather than assess learning. Why? Because assessing learning requires a series of equivalent *but* novel tests. For these clients, practitioners are also likely to conduct interviews and surveys rather than directly observe behavior (Miltenberger, Chap 2, 2012; Trejo, 2011). IncChains, of course, directly measures behavior and could supplement other direct measures of clinically relevant operant behavior (see Paule, 1994). Of particular significance, IncChains measures rates of correct and incorrect responding. These rates are likely to far more sensitively assess learning *at the level of the single-participant or client* than are percent correct measures (Binder, 1996).

IncChains has produced orderly data in our laboratory and promises to do the same in other laboratories concerned with studying variables that affect learning at the level of the single participant. A technical manual, IncChains, and related software are available here for researchers. Further research, of course, can enhance the usefulness of IncChains for practitioners. ■

REFERENCES

Baron, A., & Perone, M. (1998). Experimental design and analysis in the laboratory study of human operant behavior. In K. A. Lattal & M. Perone (Eds.), *Handbook of research methods in human operant behavior* (pp. 45-91). New York: Plenum.

Bailey, J. M., Johnson, J. E., & Newland, M. C. (2010). Mechanisms and performance measures in mastery-based incremental repeated acquisition: Behavioral and pharmacological analyses. *Psychopharmacology*, *209,* 331-341.

Baldwin, R. L., Chelonis, J. J., Prunty, P. K., & Paule, M. G. (2012). The use of an incremental repeated acquisition task to assess learning in children. *Behavioural Processes, 91,* 103–114.

Bickel, W. K., Higgins, S. T., & Griffiths, R. R. (1989). Repeated diazepam administration: Effects on the acquisition and performance of response chains in humans. *Journal of the Experimental Analysis of Behavior, 52,* 47-56.

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

Boren, J. J., & Devine, D. D. (1968). The repeated acquisition of behavioral chains. *Journal of the Experimental Analysis of Behavior, 11,* 651–660.

Baldwin, R. L., Chelonis, J. J., Prunty, P. K., & Paule, M. G. (2012). The use of an incremental repeated acquisition task to assess learning in children. *Behavioural Processes, 91,* 103-114.

Cohn, J., & Paule M. G. (1995). Repeated acquisition of response sequences: The analysis of behavior in transition. *Neuroscience and Biobehavioral Reviews, 19,* 397-406.

Dermer, M. L., & Hoch, T. (1999). Improving descriptions of single-subject experiments in research texts written for undergraduates. *The Psychological Record*, *49*, 49-66.

Dermer, N. S., & Dermer, M. L. (2000). CHAINS: A QuickBASIC 4.5 program for studying variables affecting human learning. *Experimental Analysis of Human Behavior Bulletin, 18,* 23-27.

Fischman, M. W. (1978). Cocaine and amphetamine effects on repeated acquisition in humans. *Federation Proceedings, 37,* 618.

Galizio, M. M., McKinney, P. P., Cerutti, D. T., & Pitts, R. C. (2009). Effects of MDMA, methamphetamine and methylphenidate on repeated acquisition and performance in rats. *Pharmacology, Biochemistry and Behavior, 94,* 305-311.

Higgins, S. T., Rush, C. R., Hughes, J. R., Bickel, W. K., Lynn, M., & Capeless, M. A. (1992). Effects of cocaine and alcohol, alone and in combination, on human learning and performance. *Journal of the Experimental Analysis of Behavior*, *58,* 87-105.

Kelly, T. H., Hienz, R. D., Zarcone, T. J., Wurster, R. M., & Brady, J. V. (2005). Crewmember performance before, during, and after spaceflight. *Journal of the Experimental Analysis of Behavior, 84,* 227-241.

Makris A. P., Rush, C. R., Frederich, R. C., Taylor, A. C., & Kelly, T. H. (2007). Behavioral and subjective effects of d-amphetamine and modafinil in healthy adults. *Experimental and Clinical Psychopharmacology, 15,* 123–133.

Miltenberger, R. G. (2012*). Behavior modification: Principles and procedures* (5th ed.). Pacific Grove, CA: Wadsworth.

Paule, M. G. (1994). Analysis of brain function using a battery of schedule controlled operant behaviors. In B. Weiss & J. O'Donoghue (Eds.) *Neurobehavioral Toxicity: Analysis and Interpretation* (pp. 331-338). New York: Raven Press.

Paule, M. G., Chelonis, J. J. , Buffalo, E. A., Blake, D. J. , & Casey, P. H. (1999). Operant test battery performance in children: Correlation with IQ. *Neurotoxicology and Teratology*, *21*, 223-230.

Paule, M. G., Cranmer, J. M., Wilkens, J. D., Stern, H. P., & Hoffman, E. L. (1988). Quantitation of complex brain function in children: Preliminary evaluation using a nonhuman primate behavioral test battery. *NeuroToxicology*, *9*, 367-378.

Perone, M., & Baron, A. (1982). Age-related effects of pacing on acquisition and performance of response sequences: An operant analysis. *Journal of Gerontology, 37,* 443-449.

Rodriguez, J., Morris, S., Hotchkiss, C., Doerge, D., Allen, R., Mattison, D. & Paule, M. G. (2010). The effects of chronic methylphenidate administration on operant test battery performance in juvenile rhesus monkeys. *Neurotoxicology and Teratology*, 32, 142–151.

Thompson, D. M., & Moerschbaecher, J. M. (1979). An experimental analysis of the effects of d-amphetamine and cocaine on the acquisition and performance of response chains in monkeys. *Journal of the Experimental Analysis of Behavior, 32,* 433-444.

Trejo, D. M. (2011). *Does stimulant medication for ADHD enhance learning?: A test using the incremental repeated acquisition of responses procedure with adults who benefit from medication.* (Unpublished doctoral dissertation). University of Wisconsin-Milwaukee, Milwaukee, WI.

Weinberger S. B., & Killam, E. K. (1978). Alterations in learning performance in the seizure-prone baboon: Effects of elicited seizures and chronic treatment with diazepam and phenobarbital. *Epilepsia, 19,* 301-316.

Wright, L. K. M., & Paule, M. G. (2007). Response sequence difficulty in an incremental repeated acquisition (learning) procedure. *Behavioural Processes, 75,* 81-84.

Wright, L. K. M., Popke, E. J., Allen, R. R., Pearson, E. C., Hammond, T. G., & Paule, M. G. (2007). Effect of chronic MK-801 and/or phenytoin on the acquisition of complex behaviors in rats. *Neurotoxicology and Teratology,* 29, 476-491.

Zayac, R. M, & Johnston, J. M. (2008). Contriving establishing operations: Responses of individuals with developmental disabilities during a learning task. *Research In Developmental Disabilities*, *29*, 202-216.