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A Behavioral Account of Remembering: Precurrent Behavior and Mediation of Delayed Matching to Sample

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A BEHAVIORAL ACCOUNT OF REMEMBERING: PRECURRENT BEHAVIOR AND MEDIATION OF DELAYED MATCHING TO SAMPLE

by

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David W. Sidener

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INTRODUCTION

Memory research and theory have been dominated by cognitive psychology for half a century or more now (Delaney & Austin, 1998; Estes, 1988; Mahadevan, Malone, & Bailey, 2002; Wixted, 1998). Estes suggests that the concept of memory is much more relevant to the organization and later retrieval of stored information than it is to current behavioral performance or to that which might be observed over a very short period of time in a laboratory experiment. Following from this, cognitive psychologists claim that research programs that purport to examine the organization of information (information processing models) would be better suited to examination of memory phenomena than would behavior-analytic programs whose goals often involve the explanation of performance or behavior and often in controlled, laboratory settings (Estes, 1982). However, Wixted contrasts this cognitive view of memory, which involves stored and/or processed information, with a behavior-analytic view, which he describes as referring, not to stored information, but to the ability to behave differently based on the effects of past experience. Furthermore, Wixted then says that memory phenomena may actually be better suited to behavior-analytic research than to cognitive study because behavior analysts would be more likely to consider issues such as an individual's history of reinforcement for remembering and might be more likely to approach memory research as a search for empirical laws of behavior. Estes and Wixted would probably agree on the main points of the above definitions but would surely differ on the relative importance they each place on behavior in relation to, or as evidence of that which is remembered.

Cognitive approaches to the study of memory typically involve examination of "levels" of memory such as long-term memory (LTM) and short-term memory (STM) (Mahadevan et al., 2002; Wixted, 1998) as well as the processing steps of coding, storage and retrieval (Watkins, 1990). LTM is typically differentiated from STM by differences in the forgetting function (Nilsson, 1979) or procedurally, by the amount of time between stimulus presentation and the opportunity for recall or another performance based measure (Wixted). STM might typically refer to procedures lasting 30 s or less while LTM might examine recall over periods of hours, days or weeks. However, as Wixted suggests, the greater-than or less-than 30 s distinction is not relevant in cases such as remembering a phone number, in which the subject might rehearse the number and thus continually reset the delay interval to zero.

Cognitive researchers and theoreticians have been critical of their own work in this area (see Tulving, 1979; Watkins, 1990). Watkins has outlined a number of problems in the modern cognitive exploration of memory. First, the cognitive approach is heavily based on construction and refinement of theories of memory. Watkins proposes that this is an essential component of cognitive work in this area and that many theoreticians are skeptical of researchers who do not develop their own theories but are content merely to explore theories of others. Second, the main problem that he says comes from this overabundance of cognitive memory theory is that the theories are all mediational and thus involve a search for some sort of memory trace or storage mechanism. Finally, Watkins states, "the essential problem with mediationism and the reason for the theory quagmire it has created is that its three stages (encoding, retention or storage and retrieval) constitute a level of complexity beyond the analytic power of

experimental psychology" (p. 329). Tulving has also been skeptical of progress in the area of memory research and theorizing. He suggests that if "progress" was to be determined by the degree to which a comprehensive and cumulative theoretical framework was established, it would not be easy to say that cognitive psychology had made much of it in the last hundred years (Tulving).

If it is true that "memory theorizing is going nowhere" (Watkins, 1990, p. 328) and that little progress has been made by constructing elaborate theories of memory (Tulving, 1979) it may be time to return to the real issue at hand, namely that when organisms interact with the environment, the environment changes them in some way and the resulting altered organism behaves differently (Skinner, 1987). Cognitive memory researchers are reported to be primarily involved in a search for what it is that has changed when something has been learned or remembered - a representation, engram, or some sort of physical trace of the original stimulus (Mayer, 2003; Watkins). Skinner (1987; 1989) suggests that rather than look for the physiological product of experience, we leave that search to physiologists and concentrate our efforts on examination of the altered abilities of the changed organism – the examination of *behavior* which is psychology's true subject matter. Even some cognitively oriented researchers would agree with at least the first assertion. As Estes (1982) stated, "In fact, human memory does not, in a literal sense, store anything; it simply changes as a function of experience" (p. 188). Moving beyond the storage metaphor then, let us proceed with an account of human performance over time that looks at the altered ability of individuals to behave as a function of environment-behavior interactions.

A notable behavioral interpretation of memory is that of Palmer (1991), in which he suggests that researchers should address "remembering" rather than "memory" since the latter is not a helpful or even a coherent concept and it "usurps the role of explanation and impedes the search for controlling variables for current behavior" (p. 261). "Remembering," according to Palmer, could be better described as involving one of two classes of contingencies: It is either an issue of stimulus control or one of problem solving. In the former case, that of stimulus control, we are likely to experience such memories as "spontaneous" or in other words, we may find ourselves behaving somewhat automatically. When one has learned to name a car or a tree, the names are produced seemingly automatically given the appropriate stimuli; likewise with the behaviors of walking, driving and swimming. These types of behavior are all likely shaped by direct contact with the relevant contingencies and are under the stimulus control of particular features of the environment. Because one walks, swims or says "car" only in the presence of specific stimuli, these may easily be seen to involve stimulus control. Because they involve behavior that we can do currently, but represent learning that has occurred some time in the past, they may also be seen to involve remembering.

In terms of Palmer's analysis, problem solving is more relevant to the current discussion. When an individual is confronted with an opportunity to remember and does not have current access to all of the necessary variables, he or she engages in "precurrent" behavior of generating supplementary discriminative stimuli until one such stimulus is sufficient to occasion the answer to the current problem. Skinner defined precurrent behavior as behavior that functions "mainly to make subsequent behavior more effective" (Skinner, 1968, p. 124). The process of remembering as an instance of problem solving

then involves generating supplementary stimuli until one such stimulus allows solving of the problem and then recognition that the correct answer is now available or that the problem is now able to be solved. This recognition then allows the individual to stop generating supplementary stimuli and to emit the correct response. Palmer's conceptualization of memory as a problem solving exercise closely follows that of Skinner (1953; 1968).

If remembering involves the development of stimulus control and/or problem solving, what of forgetting? Malott and Suarez (2003) state rather succinctly: "Forget forgetting – it doesn't exist" (p. 122). These authors echo sentiments similar to those suggested earlier by Skinner (1953; 1974) and Palmer (1991) that "forgetting" involves either the "failure of a discriminative stimulus to occasion a response" (Palmer; p. 267) or that competing responses have interfered with the emission of the correct or "remembered" response. The traditional approach to forgetting is that it is a decline in the ability to respond or to produce information as a function of time. However, according to Palmer there is not currently any evidence of a process through which stimulus control weakens simply through the passage of time. In fact, Skinner (1960) illustrated in at least one situation that "forgetting" was a function of extinction and not simply the passage of time. The idea of response competition is consistent with both behavioral conceptualizations and traditional models such as retroactive and proactive interference (Watkins, 1990; Wixted, 1998) in which learning interferes either with something learned earlier or something that will be learned later. Regarding memory as a behavioral process suggests that "remembering" and "forgetting" are better described as learning phenomena than as "abilities" or as physical entities. Thus, as Mahadevan et al.

(2002) have said, "the construct of memory is not required in order to understand remembering" (p. 3).

Much of what we call learning can be seen as involving some sort of remembering, as in when a stimulus comes to control a response and later encounters with that same stimulus elicit or evoke similar responses (Wixted, 1998). Matching to sample (MTS) is a family of experimental procedures that have been used extensively to study a wide variety of learning phenomena in humans and non-humans (Saunders & Williams, 1998). MTS is a type of conditional discrimination procedure, in which a sample stimulus (conditional stimulus) alters the function of other stimuli, the discriminative stimulus (S+) and the S delta (S-; Saunders & Williams). A variety of MTS procedures have been developed and used in non-human as well as human experimental preparations[1]. A typical arrangement of simultaneous MTS involves the presentation of a sample stimulus (often the center key on a three-key array), a response to the sample key (observing or orienting response) that turns on the comparison stimulus keys, and a response to one comparison key that has some property in common (often color) with the sample key (Cumming & Berryman, 1965; Saunders & Williams). This arrangement is called "simultaneous matching" because the sample key remains visible after the comparisons have appeared and both sample and comparison stimuli are simultaneously visible. Simultaneous matching is perhaps the simplest MTS arrangement. Other arrangements based on this framework arrange such contingencies as the training of a number of color matches then testing for generality of responding to "sameness" (identity MTS; see [Holth, 2003] for a discussion of "identity"); providing reinforcement for selection of the comparison that is *not* similar to the sample (oddity

MTS or non-matching to sample); or reinforcing selection of comparisons that have some sort of consistent relation to the sample such as "brighter than," or "rotated 90 degrees clockwise" (relational MTS; see Lowenkron, 1984). Other variations of the basic MTS preparation include changes in temporal arrangements. An arrangement similar to that described above, but in which the orienting response (response to the sample stimulus) turns on the comparison stimuli and turns off the sample stimulus is called zero delay MTS (Cumming, Berryman, & Cohen, 1965). Delayed match to sample (DMTS) procedures are similar to zero delay procedures but insert various intervals of time between the offset of the sample stimulus and the onset of the comparison stimulus (see Blough, 1959; Cumming & Berryman; Lowenkron, 1988; Saunders & Williams). In typical DMTS arrangements, simultaneous and/or zero delay matching is established first, then delay intervals may be introduced and increased as performance criteria are reached (Ferraro, Francis, & Perkins, 1971; Merle et al, 1998; Sargisson & White, 2001).

Many, if not all, DMTS experiments have been influenced by the classic study in this area, that of Blough (1959). In this study, utilizing a DMTS arrangement very similar to that described above, reinforcement was provided for pigeons' selection of comparison stimuli (either steady or flickering lights) that were similar to the original sample stimulus (also either a steady or a flickering light). Delay intervals ranged from 0 to 10 s. Blough observed that two of the four pigeons independently developed sample-specific behavior chains during delay intervals. These two birds were then able to perform DMTS selections at significantly higher percentages correct than the birds that did not emit these chains. It was Blough's conclusion that the sample-specific, response chains performed a "mediation" function that essentially provided supplementary

stimulation during the delay interval and up to the point of comparison selection. One of these "differentially mediating" birds responded correctly on greater than 90% of the trials, at delays of up to 10 s, but only when a sample-specific mediating behavior was performed.

Recent behavior-analytic studies of relevant human behavior include examinations of DMTS and investigations of precurrent behavior. Parsons, Taylor and Joyce (1981) described three ways in which precurrent behavior can make "subsequent" or current behavior more effective. First, the precurrent response "can alter the probability that the organism makes functional contact with the discriminative events controlling the current operant (p. 253)." Examples of this include observing, orienting and attending responses. Second, the precurrent response can alter the probability of reinforcement for another response. In a study by Polson and Parsons (1994) college students earned points by pressing either the right or the left key of a computer mouse. In the "no precurrent contingency condition", right key-presses were reinforced with .02 probability and left key presses had no scheduled consequences. During the "precurrent contingency condition" left key-presses had the effect of changing the reinforcement schedule for right key presses to .08 for 15 s. Thus the precurrent response, left key presses, changed the reinforcement schedule for right key presses and made them "more effective" in terms of increasing the reinforcement that was available. Finally, in the third type of precurrent behavior, the precurrent operant response accomplishes a prompting or mediating role that facilitates correct performance and thus reinforcement for the subsequent, or "current" response. It is this third type of precurrent contingency that is most relevant to the current investigation.

Parsons (1976) examined the ability of children (4.2 – 5.1 y.o.) to solve numeric matching problems with and without precurrent (counting) behavior. In the first baseline condition (differential "reinforcement" for correct responses), mean correct performance across all five children was 50.4%. When overt counting was trained, correct responding increased to an average of 97%. Thus, contingent provision of tokens and praise following correct responding (results did not indicate that *reinforcement* had occurred) was not enough to bring about an adequate change in behavior.

In a later study, Parsons, Taylor and Joyce (1981) trained three groups of 5-year olds to perform a brief-interval DMTS task under one of the following conditions: common collateral behavior (regardless of the stimulus presented always press top key on a five-key, "Greek Cross" array); non-differential collateral behavior, (press either top or bottom key); and differential collateral behavior, (press either the top or bottom key depending on the original sample stimulus). In study 1 they found that children who performed a sample-specific task (differential collateral behavior) were better able to match following a 0.1 s delay than children who were in either the common or non-differential collateral response groups. One child out of four in the common collateral response group learned to match at the 90% criterion after two sessions. Demonstrating a response acquisition pattern similar to the common collateral response child who met criterion, 3 out of 4 children in the non-differential collateral response group met the 90% criterion within 4 sessions at the same delay interval. One child consistently responded at about chance levels. Of the 4 children in the differential collateral response group, 3 began the DMTS condition with criterion-level responding and thus needed no training. One child in this group never responded at levels above chance. Study 2 was conducted

with only the children who met the mastery criterion of 90% or greater correct responding in study 1 (one child from the common collateral response group and three each from the non-differential and differential collateral response groups). This study found that only children in the differential collateral response condition were able to perform DMTS tasks at criterion level with delay intervals of 5 or 10 s.

In a related study, Lowenkron (1988) trained four adolescents with mental retardation to code two-dimensional shapes by creating hand signs that were visually similar to each shape. For example, one of the two-dimensional stimuli appeared similar to a stylized "W". The hand sign that corresponded to this symbol was a vertically positioned hand with the index, middle and ring fingers extended and slightly splayed. Each other shape corresponded in a similar manner to a unique hand sign that bore some visual similarity to the shape. These hand signs were maintained during the delay interval in a DMTS task and resulted in the participants being able to correctly select comparison stimuli after longer delays than without the hand signs.

Torgrud and Holborn (1989), in a systematic replication of the study by Parsons et al. (1981), examined the ability of 5-year-old children to match to sample after delays of 1, 3, 5, 10, and 15 s. In this between-groups study (additional within subject control was applied to one participant), the authors compared the effects of a common mediating task with those of a differential mediating task. The differential mediating task consisted of pressing the top key on a 5-key "Greek Cross" array if the sample stimulus color was red, and the bottom key if the sample stimulus was green. The common mediating task consisted of pressing the top key regardless of the sample stimulus color. Although group sizes were small (n=2) these researchers found that the children who performed a

stimulus-specific task (differential mediating task) during the delay interval were able to respond correctly at or near 100% for intervals up to 15 s. Comparable results were observed when the task involved oddity matching. Children who did not perform differential mediating tasks were not able to perform DMTS tasks over increasing delays.

The above studies (see especially Parsons, Taylor & Joyce, 1981; Torgrud & Holborn, 1989) provide evidence for the effects of stimulus-specific responses in mediating DMTS tasks. However, both studies used primarily between-groups designs with relatively small groups (Parsons et al. used groups of four; Torgrud & Holborn used two groups of two, but one child from each group left the study early). The current studies (Experiments 1 and 2) systematically replicated the procedures of Torgrud and Holborn. Changes from the original study include the exclusive use of within-subjects controls as well as the use of a sufficient number of participants such that conclusions about the results may be that much more convincing. Additionally, a follow-up investigation (Experiment 3) examined whether the precurrent response could be reduced (performed by the participants and then hidden from their view; see Skinner, 1953[2]) and still function to effectively mediate delays. This hidden precurrent response in Study 3 effectively produced only proprioceptive stimuli and eliminated visual stimuli from any role in the post-delay selection response. Although still involving physically apparent, and thus potentially observable responses, these hidden precurrent responses more closely approximated covert behavior. Thus, the current study examined whether simple motor responses (and/or their resulting response products) could effectively mediate a delay between a sample stimulus and a comparison stimulus, even when those responses/stimuli are not visually apparent.

METHOD

Participants, Apparatus and Setting

The current studies were completed by a total of 8 participants. Three children were assigned to and completed Experiment 1, two were assigned to and completed Experiment 2, and three children were assigned to and completed Experiment 3. In addition to these children, one child did not complete Experiment 1 because of a school placement change, one child withdrew from the study, one was excused by the experimenter because of non compliant and uncooperative behavior, two children did not complete Experiment 2 because of school placement changes and one child was excused from Experiment 3 because a consistent, chance-level baseline was not established. All participants were neuro-typically developing (i.e., not developmentally disabled) 5-year-old pre-school and/or kindergarten students and were recruited from community pre-schools and day-care centers. Written informed consent was obtained from parents and assent was obtained from participants prior to beginning the study. Participants who were excused from the study were simply told that they were finished and were thanked for their participation.

Apparatuses that were used included 2 IBM-PC compatible laptop computers with 33.8cm TFT and 30.7cm TFT displays, a separate numeric keypad (modified by removing all keys except 2, 4, 5, 6, and 8, thus leaving a Greek Cross, or top-bottom-left-right-center pattern) hand-scored data sheets and a custom developed program that did the following: presented color samples; presented a distracter task (random single digit numbers at a rate of approximately 1 per s); recorded occurrence of mediating task; presented comparison stimuli; and recorded correct or incorrect selection responses. All

probe sessions were videotaped. The first two training sessions were videotaped for the purposes of training investigators. Specific data collected by hand and by computer included number of occurrences of the mediating response, performance during the rehearsal prevention task (hand-scored data only), correct and incorrect comparison stimulus selection, and key position (left or right) of selection (hand-scored data only).

Sessions were conducted in a separate room or in a quiet area within a classroom in the child's school. One child was present for each session. The child was seated at a small table immediately in front of the laptop computer. A tri-fold poster board screen (91.4cm x 121.9cm) was placed on the table and behind the computer. The experimenter was seated next to the child. An additional observer was seated behind the child when interobserver data were collected. Sessions lasted between 30 and 45 min and were conducted between 1 and 4 times per week. Within each session, children worked on the experimental tasks for about 8-12 min and then were allowed a 2.5-min play break. During the breaks, children played with toys and/or consumed edibles provided by the experimenter. Prior to the experiment, parents submitted lists of preferred, non-preferred and restricted toys and/or edibles.

Design and Data Collection

Each of the three studies used within subject research designs that consisted of multiple baseline designs across participants and with reversals. Experiments 1 (consisting of phases A-B-C-A) and 2 (phases A-C-A) were complementary in that Experiment 2 was designed to control for any possible B-C order effects in Experiment 1. Experiment 3 (A-B-C-A) was a stand-alone study that also employed a multiple baseline across participants with reversal.

Dependent Variables

Primary dependent variables during probe sessions included percentage of correct comparison stimulus selection, performance of mediating task (Common Mediating Response and all Differential Mediating Response conditions), and performance of rehearsal prevention task.

Interobserver Agreement

Interobserver agreement (IOA) data were collected in over 44% of sessions. An agreement was scored when both the primary and secondary data collectors marked either (+) or (-) indicating correct or incorrect comparison selection responses. The point by point IOA method was used, in which IOA was calculated based on the outcome of each trial. IOA was calculated by dividing agreements by agreements plus disagreements and multiplying by 100. IOA ranged from 95 to 100% and averaged 99.7%.

Stability and Mastery Criteria

Stability was defined as two or more consecutive data points in which a majority of the data paths did not appear to show a trend, and was assessed through visual inspection of graphical displays. For mastery criteria (all Differential Mediating Response conditions), responding was required to be at or above the following for two consecutive sessions, with a minimum of three total sessions and across a majority of data paths (all three data paths in Experiment 3): Experiment 1 – 85%; Experiment 2 – 75%; and Experiment 3 – 86%. Different criteria were necessitated by the varying number of trials per session in each of the three experiments.

General Procedures

Throughout each training and probe phase, correct responses were followed by an indicator sound (computer-generated tone), delivery of a token and brief praise. Tokens were placed on one of a series of 7 randomly chosen token boards whose average value was 20. Each time a token board was filled the child was given a play break and the experimenter replaced the token board with one with a different value. During play breaks participants were allowed to play with toys or consume edibles, as they chose. Incorrect responses were followed by the absence of the tone, token and praise, a brief inter-trial interval and presentation of the next trial.

Assessment

During the first session, children's abilities to tact colors (blue and red) and to read numbers (1-10) were assessed. During the first session of study 3, children's abilities to show a "thumbs-up" and to cross their fingers were also assessed.

Training

Prior to baseline children were taught to select comparison stimuli by pressing the key on the keypad that corresponded to a color image on the computer screen, to select a comparison under a simultaneous then a zero delay arrangement, to read the numbers 1-10 as they appeared on the computer screen and to select a comparison under a 0.5 s DMTS arrangement. Each of these training steps was performed at 90% or greater by all participants prior to the beginning of baseline probe sessions.

Baseline

Children were shown color "sample" stimuli on a computer screen and after a variable delay (1 to 15 s) they were asked to choose similarly colored "comparison"

stimuli by pressing a key on a numeric keypad. Both sample and comparison stimuli were either red or blue squares.

EXPERIMENT 1

Each probe session consisted of 40 trials – 8 at each of the intervals, 1, 3, 5, 10,and 15 s.

Experimental Conditions

Common Mediating Response

Following baseline, children were taught to perform a mediating task during the delay interval. The common mediating task was non-specific with regard to the color of the sample stimulus. That is, the common mediating task consisted of pressing the number 5 on the numeric keypad (center key) following the presentation of either the red or the blue color sample. Comparison selections were made after the delay interval elapsed.

Differential Mediating Response

During the next phase children were taught to perform a stimulus-specific mediating task during the delay interval. This differential mediating task consisted of pressing the top keypad key in the presence of the red sample and pressing the bottom key in the presence of the blue sample. As above, comparison selections were made after the delay interval elapsed.

Return to Baseline (Mediating Response Prevention)

This phase involved exposure to the same conditions as in baseline above. Children were told that they were not to press any keys during the delay interval. In addition, access to the numeric keypad was blocked until the comparisons appeared.

Experiment 1 Results

The results for each participant in Experiment 1 are depicted in Figure 1. As seen in the upper panel, Kevin's responding was variable and at approximately chance levels during baseline, common mediating response and the return to baseline conditions. He reached mastery criterion (85% or greater correct responding across a majority of data paths for two consecutive sessions) during the 6th session in the differential mediating response condition (session 12 overall). The means (percentage correct) for each of Kevin's experimental conditions were as follows: baseline, 46% (*SD*=19); common mediating response, 50% (*SD*=12); differential mediating response, 70% (adjusted - 95%) (*SD*=28; adjusted=12); and return to baseline, 60% (*SD*=19). Adjusted means and standard deviations consist of the results of the last two data points of a phase in which there was visual evidence of unstable data. As seen in the middle panel, Alice's responding was also variable and at approximately chance levels during baseline, common mediating response and the return to baseline conditions, although with a possible increasing trend in the return to baseline phase. She reached mastery criterion during the 3rd session in the differential mediating response condition (10th session overall). The means for each of Alice's experimental conditions were as follows: baseline, 40% (*SD*=23); common mediating response, 40% (*SD*=14); differential mediating response, 89% (*SD*=10); and return to baseline, 60% (adjusted – 72%) (*SD*=20; adjusted=15). There was some evidence for an increasing trend in Alice's return to baseline results. The mean percentage correct, combined across all delay intervals for this phase included 35% correct for the first session and 73% correct for the last session. Responding was variable but higher in the last session of this phase than in

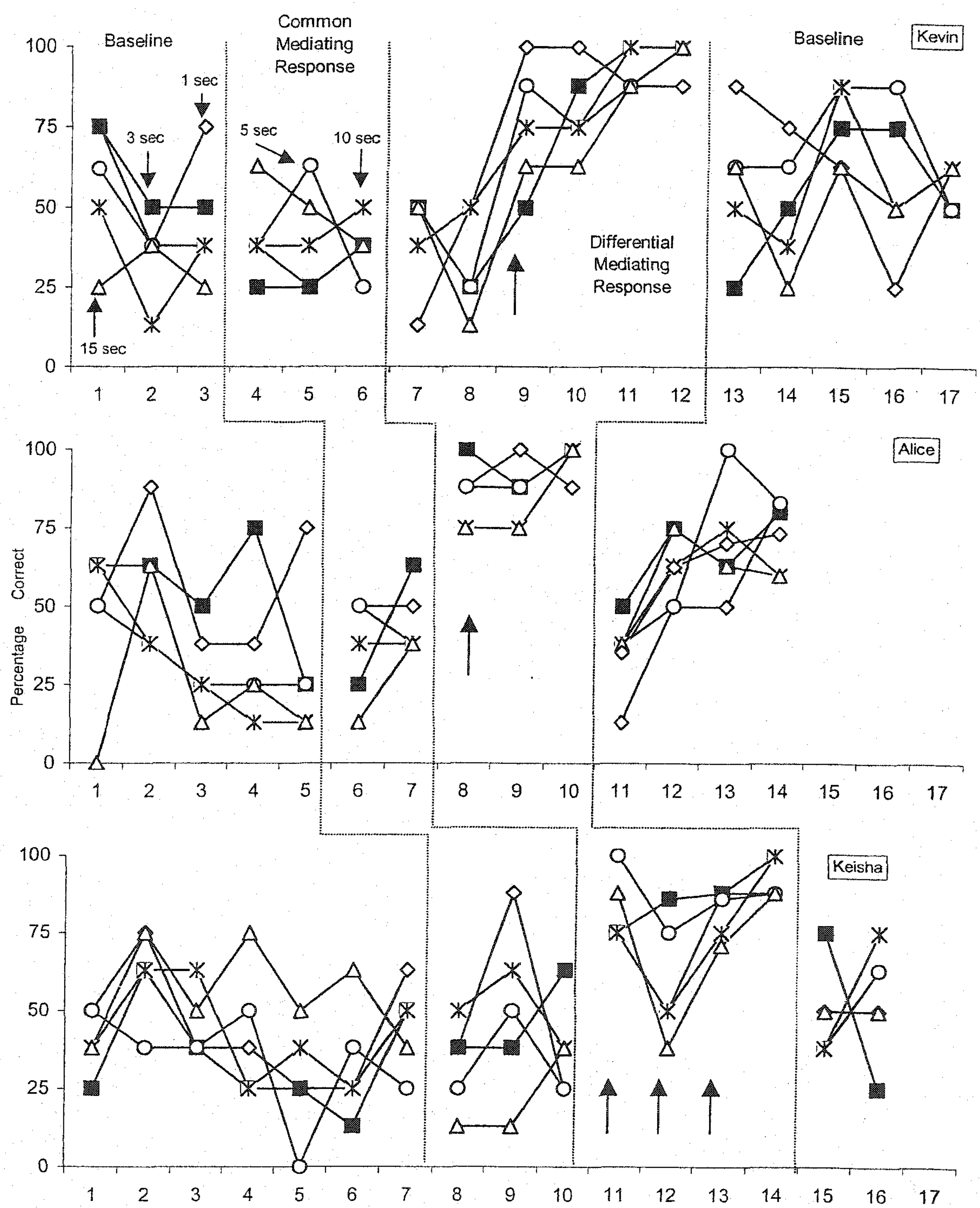

Figure 1. Primary Findings for All Participants in Experiment 1. Percentage of correct responses across each experimental phase.

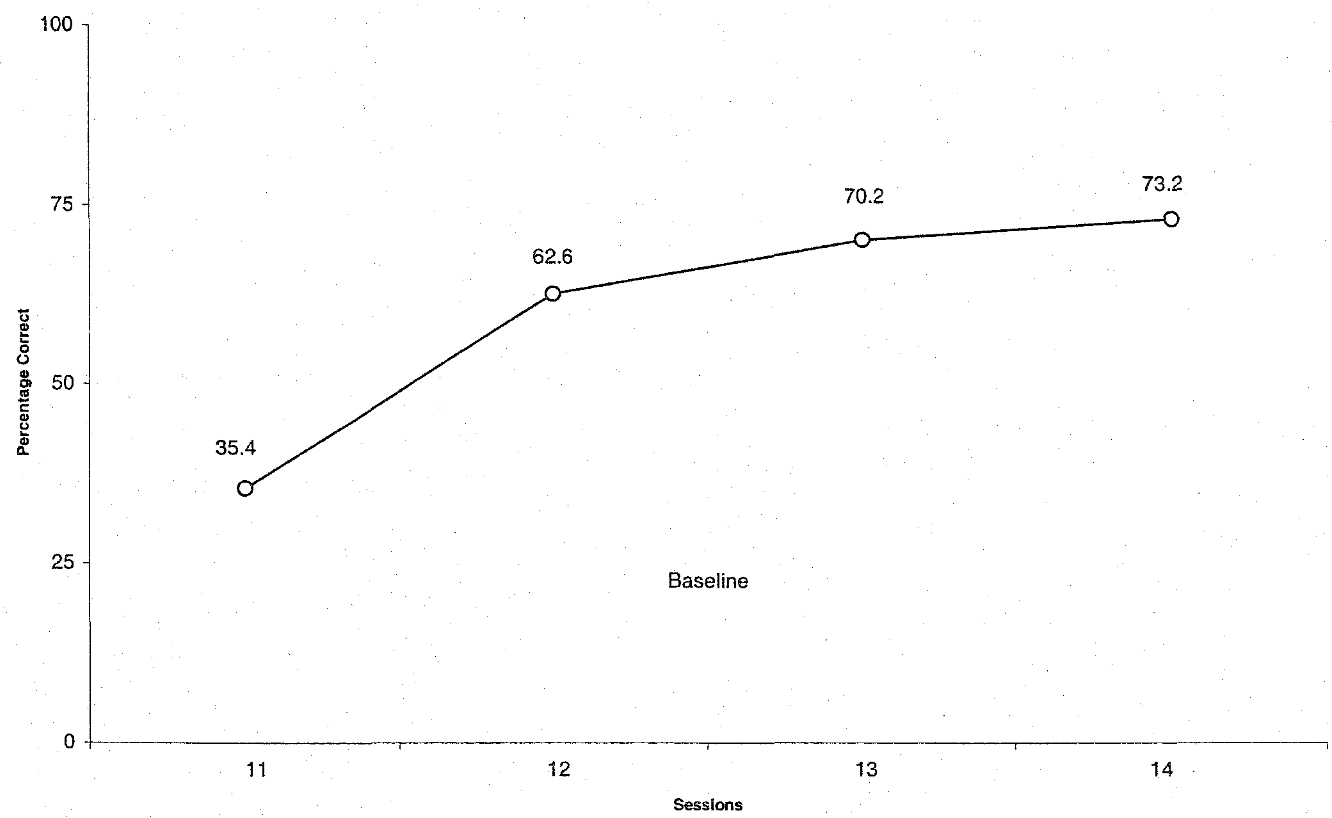

Figure 2. Average Correct Responses for Alice During Return to Baseline.

the first for each delay interval. As seen in the lower panel, Keisha's responding was also variable and at approximately chance levels during baseline, common mediating response and the return to baseline conditions. She reached mastery criterion during the 4^{th} session of the differential mediating response condition (14^{th} session overall). The means for each of Keisha's experimental conditions were as follows: baseline, 42% (*SD*=18); common mediating response, 40% (*SD*=20); differential mediating response, 79% (adjusted - 87%) (*SD*=17; adjusted=9); and return to baseline, 51% (*SD*=16).

Experimental control by the differential mediating response (rather than the addition of tokens or partial contingency statements) is demonstrated for both Kevin and Keisha by the results of the return to baseline phase. For both of these participants, results for these phases were similar to those of the original baseline.

Experiment 1 Discussion

The major finding of Experiment 1 was that correct comparison selections on DMTS tasks with delay intervals of 1 s or more required sample-specific, differential precurrent behavior (differential mediating response condition). Correct selections following a mediating response that was not sample-specific (common mediating response condition) occurred at approximately chance levels and were similar to those seen during both the baseline and return to baseline conditions. The results of Experiment 1 replicated major findings of previous research in this area (Parsons, Taylor, & Joyce, 1981; Torgrud & Holborn, 1989).

A likely interpretation of this effect is that the sample-specific stimulus (finger on the top key always went with "red," finger on the bottom key always went with "blue") provided supplementary stimulation that was part of a conditional discrimination for the

selection of a unique comparison stimulus (Mackay, 1991). Indeed, during differential mediating response probe sessions ancillary behavior was observed that would support this interpretation. Each of the participants was seen on at least one trial to lift his or her index finger from the keypad as the interval ended and the comparison stimuli appeared on the computer screen, look at the comparison selections *and then place his or her finger back on the mediating key which he or she had just been pressing and immediately make the correct selection*. Thus returning the finger to the keypad (re-emitting the mediating response) in the just-left position likely served the function of generating the missing stimulus which, when present, allowed correct comparison selection (Skinner, 1953).

As indicated under "Results," Alice's performance appeared to improve across subsequent sessions of the return to baseline condition. Combined performance across all delay intervals ranged from 35% correct (first session) to 73% correct (last session), although these data did not show a smooth linear increase (see Figure 2). Visual inspection of these averages indicates that improvements might have been reaching asymptote, or "leveling off" in the range of 75%. As described by Saunders and Williams (1998), 75% correct matching in the case of two choice MTS models requires further analysis. There are at least three possible interpretations of these findings. The first is that one discrimination is performed at 100% while the other still occurs at chance levels (e.g., when the sample is red, the red comparison is always selected, while when the sample is blue, blue is chosen in 50% of the trials and red is chosen in 50%). A second interpretation is that, as above, one sample always produces correct selections while the other produces a position bias. As above, this performance would generate

approximately 75% correct selection. The final possibility is that intermediate accuracy represents progress toward full discrimination and is indicative of improved performance in the presence of both stimuli. A further review of Alice's raw data indicated that she responded incorrectly on a number of both red and blue trials and did not seem to demonstrate any position bias. Thus, the best account of her performance during these baseline sessions seems to be the third possibility, namely that she performed at above chance levels without a stimulus or position bias. When experimenters queried the participant about employing any strategies to mediate delayed selections, she said she was not. When asked if she was covertly rehearsing a tact of the sample stimulus[3], she replied that when the comparisons appeared she would, "Just think it (the correct comparison) in my head." Unfortunately, while it may have proved helpful to gather more data under this condition, the participant was unwilling to conduct further sessions.

A few minor procedural irregularities occurred during Experiment 1, however, it appears that these irregularities do not pose a threat to the internal validity of the findings. As described above, it was originally intended that all probe sessions would be conducted under extinction. However, due to particular patterns of participant responding, it was decided to deliver tokens and brief praise statements following correct responses during probe sessions. This change occurred after 2 Differential Mediating Response sessions for Kevin, after 1 for Keisha, and between Common Mediating Response and Differential Mediating Response conditions for Alice (see arrows on Figure 1). The addition of tokens did not result in improved performance for Keisha. In fact, after the first Differential Mediating Response session her performance worsened. Because Keisha required many additional prompts while learning to make use of the mediating response,

experimenters prompted her during probe trials, after comparisons appeared and before making a selection, by saying either, "Top goes with…" or "Bottom goes with…" while Keisha completed the statement. These prompts were given in Differential Mediating Response session 1, not given in session 2 and given again in session 3. During session 4, the experimenter did not prompt but paused to allow Keisha to emit one of the above statements prior to making a selection.

One of the questions that remains after consideration of the procedures and findings of Experiment 1 is that of the relative functions of and possible relationship between the procedures associated with the Common Mediating Response and Differential Mediating Response conditions. As noted above, responding under the Common Mediating Response condition produced results similar to those seen in the Baseline conditions while the Differential Mediating Response condition produced criterion-level responding. Experiment 2 was designed in order to rule out the possible order effects (B-C) of always following Common Mediating Response sessions with Differential Mediating Response sessions.

EXPERIMENT 2

Procedures were similar to those described above under Experiment 1. Experiment 2 was designed to control for any possible order effects of the common mediating response and differential mediating response conditions from Experiment 1. Experiment 2 controlled for this possibility by eliminating the common mediating response condition. Additionally, Experiment 2 involved fewer trials per probe, with each probe consisting of 20 rather than 40 trials, or 4 trials at each of the delay intervals (1, 3, 5, 10, and 15 s).

Experiment 2 Results

The results for each participant in Experiment 2 are depicted in Figure 3. As seen in the upper panel, Joe's responding was variable and at approximately chance levels during baseline and the return to baseline conditions. He reached mastery criterion (75% or greater correct responding across a majority of data paths for two consecutive sessions and a minimum of three total sessions) during the 3rd session of the differential mediating response condition (6th session overall). The means for each of Joe's experimental conditions were as follows: baseline, 47% (*SD*=31); differential mediating response, 100% (*SD*=0); and return to baseline, 60% (*SD*=27). As seen in the lower panel, Jay's responding was also variable and at approximately chance levels during baseline and the return to baseline conditions. He reached mastery criterion during the 5th session of the differential mediating response condition (10th session overall). The means for each of Jay's experimental conditions were as follows: baseline, 48% (*SD*=26); differential mediating response, 88% (adjusted - 93%) (*SD*=19; adjusted=12); and return to baseline, 47% (*SD*=31).

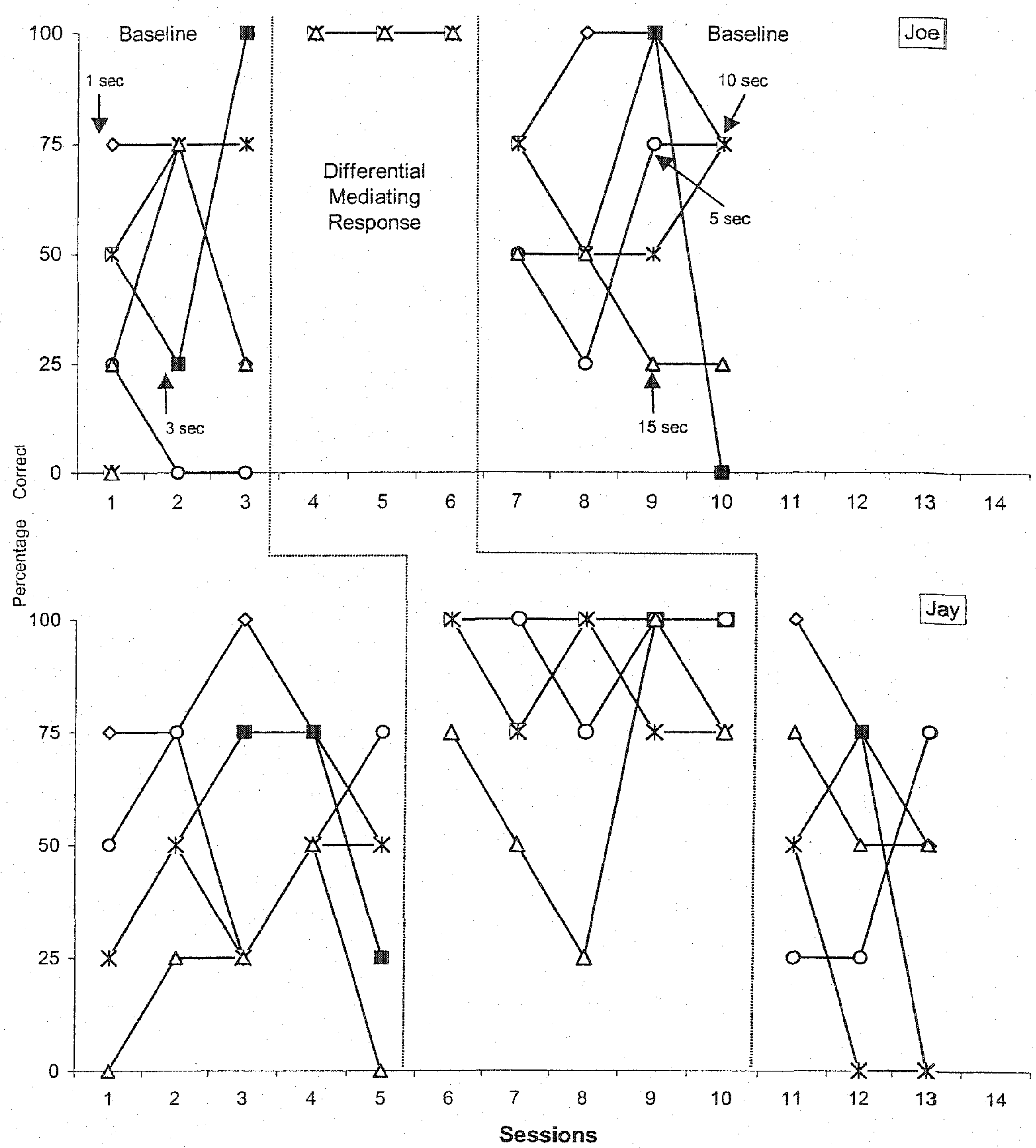

Figure 3. Primary Findings for All Participants in Experiment 2. Percentage of correct responses across each experimental phase.

Experiment 2 Discussion

The results of Experiment 2 provided further support for previous findings in this area (Parsons, Taylor, & Joyce, 1981; Torgrud & Holborn, 1989) as well as those of Experiment 1 in the current study. Major contributions of Experiment 2 include further evidence that not only was precurrent behavior required in order for children to respond at or above criterion levels on the DMTS tasks, the precurrent behavior must be sample-specific and improved performance during the differential mediating response condition did not seem to rely on or benefit from prior exposure to the common mediating response condition.

EXPERIMENT 3

Pre-baseline training and baseline conditions were similar to those described above. Training procedures described above were modified as follows: differential mediation that previously involved key presses was changed to hand positioning as described below. Additionally, the 1-s and 3-s delay intervals were eliminated. Each probe session consisted of 21 trials, or 7 trials at each of the delay intervals, 5-s, 10-s, and 15-s.

Experimental Conditions

Differential Mediating Response: Visible

As above, children were taught to perform a stimulus-specific, differential mediating task during the delay interval. The differential mediating tasks for this experiment were as follows: given a red sample, cross the index and middle fingers of the left hand; and given a blue sample, make the left hand into a fist with thumb up.

Differential Mediating Response: Not visible

Children were taught to perform the same stimulus-specific task and in addition, place the mediating hand behind their back.

Return to Baseline (Mediating Response Prevention)

This phase involved a return to baseline conditions described above. Children were prompted to place and hold both hands flat on the table in front of them during the delay interval. As above, after the delay they selected a comparison via the numeric keypad.

Experiment 3 Results

The results for each participant in Experiment 3 are depicted in Figure 4. As seen in the upper panel, Julie's responding was variable and at approximately chance levels during baseline and the return to baseline conditions. She reached mastery criterion (86% or greater correct responding across a majority of data paths for two consecutive sessions and a minimum of three total sessions) during the 4th session in the differential mediating response: visible condition and continued at criterion-level performance during all sessions of the differential mediating response: not visible condition. The means (percentage correct) for each of Julie's experimental conditions were as follows: baseline, 46% (*SD*=18); differential mediating response: visible, 91% (adjusted - 100%) (*SD*=14; adjusted=0); differential mediating response: not visible, 100% (*SD*=0); and return to baseline, 65% (adjusted - 57%) (*SD*=19; adjusted=13). As seen in the middle panel, Katryna's responding was also variable and at approximately chance levels during baseline and the return to baseline conditions. She reached mastery criterion during the 4th session in the differential mediating response: visible condition and continued at criterion-level performance during all sessions of the differential mediating response: not visible condition. The means for each of Katryna's experimental conditions were as follows: baseline, 46% (*SD*=20); differential mediating response: visible, 92% (adjusted - 98%) (*SD*=10; adjusted=6); differential mediating response: not visible, 100% (*SD*=0); and return to baseline, 65% (*SD*=15). As seen in the lower panel, Jay's responding was also variable and at approximately chance levels during baseline and the return to baseline conditions. He reached mastery criterion during the 4th session of the differential mediating response: visible condition and also during the 4th session of the differential mediating response: not visible condition. The means for each of Jay's

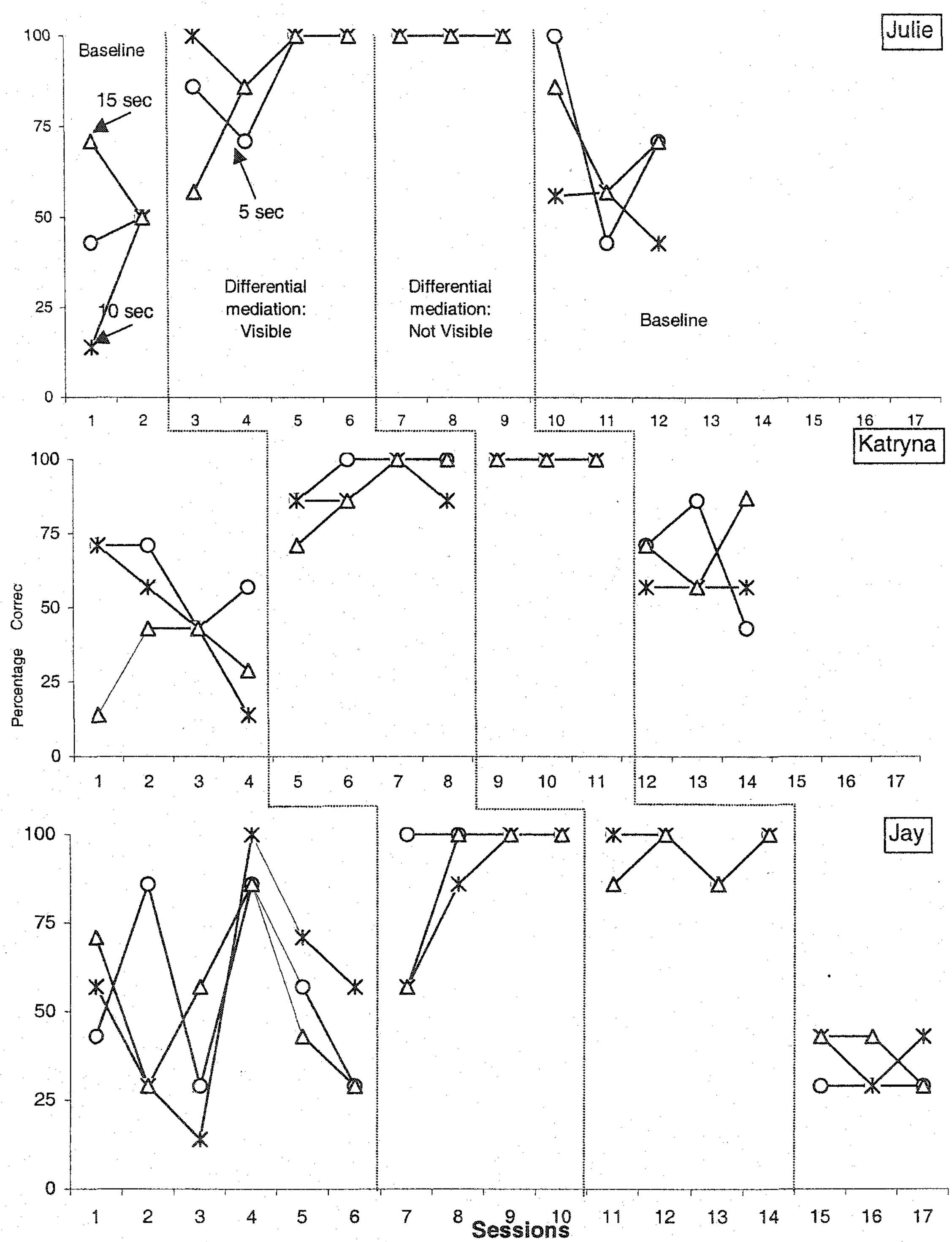

Figure 4. Primary Findings for All Participants in Experiment 3. Percentage of correct responses across each experimental phase.

experimental conditions were as follows: baseline, 54% (*SD*=25); differential mediating response: visible, 92% (adjusted - 100%) (*SD*=17; adjusted=0); differential mediating response: not visible, 95% (*SD*=7); and return to baseline, 35% (*SD*=7).

Experiment 3 Discussion

The results of Experiment 3 provided further support for previous findings in this area, such as those of Lowenkron (1988), Parsons et al. (1981) and Torgrud and Holborn (1989) as well as those of the two previous experiments in the current study. Primary contributions of Experiment 3 include further evidence that sample-specific mediating behavior may serve a "precurrent" function, that a variety of response forms may function precurrently and that the mediating behavior need not be visible in order to be effective.

In addition to demonstrating a fairly simple as well as portable mediation mechanism, Experiment 3 provides some elementary support for Skinner's (1953; 1957) assertions regarding the development of responses to covert stimuli and behavior. The development of verbal behavior descriptive of and in the presence of publicly available non-verbal stimuli, or the tact relation, is fairly straightforward (Skinner, 1957). According to Skinner, in the presence of a ball, if a child says, "Ball," it is relatively easy for the parent to confirm and thus reinforce emission of that tact. However, when the stimulus is one to which only the speaker has access, as in the case of a stomachache, the listener cannot quite so easily agree and thus provide reinforcement. This problem required a separate and more extensive analysis.

Skinner (1953, 1957) described four mechanisms by which a person may come to emit verbal behavior in response to private stimuli. The first and second he called

"public accompaniments," and "collateral responses" and might be described as outwardly visible events (physically apparent stimuli in the former case and physically apparent behavior in the latter) that typically co-occur with private events, as in the case of various pain-producing events that may also produce redness or swelling (public accompaniment), and may also cause the speaker to emit some characteristic form of behavior (collateral response) "such as holding the jaw or crying out" (Skinner, 1953, p. 259). A third arrangement involves the metaphorical generalization of descriptions of events perhaps first learned as tacts (e.g., "butterflies in my stomach"). Finally, the fourth means by which the community may be involved in the development of a repertoire regarding private stimulation is perhaps the most relevant to the current discussion: response reduction.

In *Verbal behavior*, Skinner (1957) described an arrangement in which behavior occurs that may have originally been publicly observable (and thus came to be tacted), but is now "executed so weakly or so incompletely that it fails to be seen by another person, although it is still strong enough to stimulate the behaver himself" (p. 133). In Experiment 3 of the current study, the mediating response was originally visible to the participant as well as to the experimenter (Differential Mediating Response: Visible). This arrangement allowed the experimenter to verify that the correct response was being emitted. Prior to the probe sessions, prompts and explicit reinforcement were arranged for this very purpose. In the phase that followed (Differential Mediating Response: Not Visible), the mediating response was visible to the experimenter but not to the participant. Thus the response only produced proprioceptive stimuli for the participant (Skinner, 1953) but still allowed verification and reinforcement by the experimenter. In

this case, the mediating response may be seen to have "shrunk," or become reduced in size in terms of its prominence or (visual) availability to the behaver, although not in terms of its effectiveness. An additional benefit of a procedure such as this is that the reduced or (metaphorically) private stimulus, while not visually available to the behaver, is still fully available to the listener, audience, or in the current case, the experimenter. In terms of reinforcement or confirmation that the response followed the appropriate stimulus, the experimenter was completely able to determine whether the response occurred under appropriate circumstances and could be confident that reinforcement was appropriate. This procedure then alleviates some of the weakness in the naturally-occurring account proposed by Skinner (1957) in which the listener could not be precisely sure to what stimuli the behaver was actually responding.

GENERAL DISCUSSION

The present study examined the ability of 5-year-old children to perform tasks involving what is commonly called short-term memory using brief, variable-interval DMTS tasks. A major finding of this study was that without sample-specific, differential precurrent behavior available (Baseline, Common Mediating Response, and return to Baseline conditions), children were not able to respond correctly on DMTS tasks at more than chance levels. Additionally, whether the form of the precurrent response was pressing a keypad key, forming the hand into a position that remained visible or forming a hand position that was then not visible did not matter. As was seen in each of the Differential Mediating Response conditions, only when a sample-specific precurrent response was emitted did children perform at or above criterion levels.

This study replicates and extends major findings of previous work in this area (e.g., Lowenkron, 1984, 1988; Parsons et al. 1981; Torgrud & Holborn, 1989). Previous findings were extended by replication of a similarly robust effect, namely that only when a sample-specific mediating response occurs does it influence responding (as in each Differential Mediating Response condition). Additionally, with the exclusive use of within-subject controls (combined multiple baseline plus reversal design) the findings may demonstrate stronger experimental control and have increased internal validity (Kazdin, 1982). Demonstration that the effects of the mediating task were reversible when mediation was prevented was also an extension of previous examinations in this area. Additionally, while the claim that within-subject designs are an improvement over between-groups designs may be an arguable point, they are probably more traditional for investigations such as the current one and certainly more common in behavior-analytic

research. Finally, while Experiment 1 demonstrated that the mediating response must be sample-specific in order to have an effect (that is, selection performance was not improved under the Common Mediating Response condition), Experiment 2 showed that prior training and exposure to the Common Mediating Response condition was not necessary in order for the Differential Mediating Response to have an effect. Experiment 3 provided an extension of research in this area by illustrating that the mediating response need not be visually apparent in order for it to control behavior.

The Nature of Stimulus Control in MTS

An issue to be accounted for in the current paper is how DMTS performance was accomplished using the above procedures. Before attempting to do this it might be useful to consider the mechanism through which more basic forms of MTS are effective, although this task may be more difficult than it seems. A number of authors have suggested various means through which selections may be controlled in MTS and DMTS experiments. At least four and possibly five behavioral processes relevant to the current study may be found in the literature. Cumming and Berryman (1965) considered two early hypotheses and their utility in accounting for more basic (e.g., simultaneous) MTS as well as complex (e.g., oddity or delayed) MTS processes and/or functional mechanisms. One possibility is that the sample stimulus (SS) and comparison stimuli (CO) form a stimulus compound that unitarily serves a discriminative capacity. However, this does not seem to apply in the cases of DMTS and zero-delay matching because at the time of comparison selection the original sample stimuli are no longer present and thus, a part of the compound stimulus is unavailable. The second interpretation considered by Cumming and Berryman and also discussed by Saunders and

Williams (1998) is that the SS may serve a selective or "instructional" function that becomes effective in the presence of the COs. Before discussing this possibility further it may be informative to briefly discuss the remaining possibilities. A third possibility (Saunders & Williams) which may easily be applied to exclusion learning but may have broader application as well, is that while matching performance may in some cases be a function of selection of the S+ (comparison stimulus programmed for reinforcement), in other cases it may instead be a function of rejection of the S- (comparison stimulus programmed for extinction). That is, in the latter cases a child may not learn when to choose red, but instead may learn when not to choose blue. A fourth possibility, recently proposed by Jones (2004) is that the two-CO array serves as a compound stimulus in which the S+ and the S- collaboratively serve a discriminative function. Although the third and fourth mechanisms identified above appear to be viable interpretations of the mechanism of MTS, they remain beyond the scope of the current paper. The last mechanism to be considered here bears much in common with the second, above and involves a kind of behavioral "coding" (Cumming et al. 1965; Lowenkron, 1984; 1988). Although coding may appear to be distinct from an "instructional" function, it has previously been described as functioning similarly to the selective, or instructional function described above (Cumming & Berryman, 1965; Cumming et al. 1965).

The coding, or instructional interpretation is especially relevant to accounts of performance under DMTS but has also been used to account for performance in other MTS preparations such as simultaneous matching (Cumming et al. 1965; Eckerman, 1970). Under this interpretation, the SS evokes a coding response, R^C, which then evokes a selection response, R^S. In the case of DMTS, the coding response either continues (as

in the case of ongoing eye gaze or hand positioning; Blough, 1959; Lowenkron, 1988) or produces a response product that is still available after a delay (see Lowenkron, 1984). Coding[4] has been invoked as a mediational strategy in human MTS studies, especially when a coding response has been explicitly programmed (Lowenkron, 1984; 1988; Parsons et al 1981; Torgrud & Holborn, 1989) but has also been used to describe non-programmed, response-mediated matching like that discussed by Blough. This usage of the term coding is consistent with Skinner's (1968) use of the term precurrent behavior and functions, of course, similarly to the planned behavioral mediation in the current study.

In the current study, as previously discussed, the presence of programmed differential mediating responses can account for most of the increases in comparison stimulus selection over baseline. There was, however, one exception to this - the unaccounted for improvements in Alice's responding under the return to Baseline conditions. As described earlier, Alice reported "thinking" the correct answer "in her head" prior to making selections, although she also reported at other times after having made correct selections that she had not "known" prior to selection that her choice was correct. While "thinking it in her head" is a plausible explanation in everyday language, a simpler, more parsimonious interpretation, and one similar to that reported elsewhere is that these selections were somehow mediated by a coding response and quite likely a coding response of which she was otherwise unaware. Blough (1959), of course, observed similar behavior in 2 of his 4 pigeons. Lowenkron (1984), Sidener (2003) and Torgrud and Holborn (1989) reported observation of similar "bootleg" coding behaviors, each during experimental conditions in which previously trained coding responses were

prohibited, as in the above return to baseline condition. Suspecting this possibility, experimenters observed Alice closely during these sessions for sample-specific arm-, leg-, eye- and facial-movements but were not able to identify any explicit, differential behavior such as "thumb positioning" (Lowenkron), "head tilting" (Sidener), or "eye gaze" (Torgrud & Holborn). However, with no reason to suspect that Alice was intentionally hiding a covert coding response, and in considering that her performance only reached 73% (and not 100%), if there was coding behavior that served a mediating function it was likely not behavior of which she was aware and clearly not effective on every trial.

A Conceptual Model of Remembering

The current study provides additional support for the role of operant behavior in what is usually called memory. The concept of memory, however, is not helpful (Palmer, 1991) and not necessary in order to explain remembering (Mahadevan, et al., 2002) or altered performance (Mackay, 1991; Wixted,1998). Thus, as suggested by Skinner (1953) and later by Palmer, in a behavioral account, it would be more appropriate to speak of "remembering" than of "memory". While the practices of our culture may train children to say that they think or remember things "in their heads," we do not have evidence for such a storage mechanism (Estes, 1982). On the contrary, there is evidence that remembering takes place under particular environmental conditions, many of which we are often unable to describe.

Future Directions

In light of the above findings, it might prove helpful in further determining the role of operant behavior in the process of remembering to measure more closely any

difficult to observe behavior that occurs during DMTS tasks. This would most likely involve more sensitive instrumentation than that which was used in the current investigation. Instruments could be used that measure subtle arm and leg movements as well as facial movements and even eye gaze. Other methods that might be employed could involve better prevention of possible surreptitious mediational responding, such as by restricting available visual stimuli to those seen on the computer screen and/or restricting auditory stimuli via headphones or "white noise" generators. In addition, it might prove fruitful to continue to examine more and more subtle forms of coding behavior and/or larger delay intervals that begin to span the gap between so-called short-term and long-term memory.

Conclusion

In a special edition of the *Journal of the Experimental Analysis of Behavior* dedicated to "Future Directions in Behavior Analysis", Marr (1984) suggested that behavior analysts apply their efforts, methods and philosophical orientations toward the experimental analysis of complex human operant behavior. But, have we not done so thus far? Marr seems to think not. These sentiments are echoed elsewhere by others as well. DeGrandpre (2000) states, "operant principles represent today only a marginal force in contemporary psychological science" (p. 721). Not surprisingly, cognitive psychologists have made similar claims (Dember, 1974; Johnson-Laird, 1988; Miller, 1988). The fact of the matter is that behavioral psychology has laid out a framework for the conceptualization of human behavior that is not as well regarded today within the mainstream of psychology as it might be (DeGrandpre; Marr). It is sometimes claimed that reasons for this may be found in the methods of behavior analysis (Marr; Dember)

which caution the behavioral psychologist against speculation and steer him toward discovering truths that are observable and measurable (Skinner, 1987). Other claims involve the scope of behavioral psychology, which some suggest is best suited to utilitarian applications such as behavior modification (Baars, 1988; Barsalou, 1992). Although vaguely defined processes such as "memory" may not be easily observable or measurable, the current study provides support for claims that behavioral events involved with remembering can be arranged, observed and measured. There is no reason to suspect that behavior analysts cannot continue to develop means by which to examine increasingly complex and subtle human behavior.

Appendix A

Footnotes

1. For the sake of brevity only those most relevant to the current study will be discussed here. For more comprehensive coverage see Mackay, 1991 and Saunders & Williams.
2. Skinner argued that there are a number of ways that people come to behave with respect to "private stimuli", or stimuli to which only the behaver has access. One of these he termed "response reduction". In this type of arrangement, a person first learns to tact outwardly accessible behavior through contact with the environment and via reinforcement from the verbal community. For example, a girl says, "I am going home" in the presence of visible stimuli such as putting on her coat and gathering her belongings. Later, after this response is appropriately reinforced and may be executed with some strength, she may say, "I'm thinking of going home" when she observes some private responses that have in the past corresponded to the outwardly visible responses. The hidden precurrent responses in Experiment 3 represent behavior that is less physically apparent to the behaver but is not fully private in the sense of only being observable to the behaver.
3. Experimenters asked Alice if she was "saying the color name to herself" or doing anything else to try to remember the color.
4. This interpretation relies on a definition of coding as an instance of behavior and is distinct from the hypothetical cognitive memory construct, "encoding".

Appendix B

Human Subjects Institutional Review Board Approval

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Centennial
1903-2003 Celebration

Date: February 6, 2003

To: Jack Michael, Principal Investigator
David Sidener, Student Investigator for dissertation

From: Mary Lagerwey, Chair Mary Lagerwey

Re: HSIRB Project Number 02-11-10

This letter will serve as confirmation that your research project entitled "Mediation of Delayed Matching to Sample in Children" has been **approved** under the **full** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: November 27, 2003

BIBLIOGRAPHY

Baars, B.J. (1988). A *cognitive theory of consciousness*. New York: Cambridge.

Barsalou, L.W. (1992). *Cognitive psychology: an overview for cognitive scientists*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Blough, D.S. (1959). Delayed matching in the pigeon, *Journal of the Experimental Analysis of Behavior, 2,* 151-160.

Cumming, W.W., & Berryman, R. (1965). The complex discriminated operant: Studies of matching-to-sample and related problems. In D.I. Mostofsky (Ed.), *Stimulus generalization* (pp. 284-330). Stanford, CA: Stanford University Press.

Cumming, W.W., Berryman, R., & Cohen, L.R. (1965). Acquisition and transfer of zero-delay matching. *Psychological Reports, 17*, 435-445.

DeGrandpre, R.J. (2000). A science of meaning. *American Psychologist, 55*, 721-739.

Delaney, P.F. & Austin, J. (1998). Memory as behavior: The importance of acquisition and remembering strategies. *The Analysis of Verbal Behavior, 15*, 75-91.

Dember, W.N. (1974). Motivation and the cognitive revolution. *American Psychologist, 29*, 161-168.

Eckerman, D.A. (1970). Generalization and response mediation of a conditional discrimination. *Journal of the Experimental Analysis of Behavior, 13*, 301-316.

Estes, W.K. (1982). Is human memory obsolete? In W.K. Estes (Ed.) *Models of learning, memory and choice: selected papers,* (pp. 172-191), New York: Praeger.

Estes, W.K. (1988). Human learning and memory. In R.C. Atkinson, R.J. Herrnstein, G. Lindzey, & R.D. Luce (Eds.) *Stevens handbook of experimental psychology, 2nd Edition,* (pp. 351-415), Toronto: John Wiley and Sons.

Ferraro, D.P., Francis, E.W., & Perkins, J.J. (1971). Titrating delayed matching to sample in children. *Developmental Psychology, 5,* 488-493.

Holth, P. (2003). Generalized imitation and generalized matching to sample. *The Behavior Analyst,* 26, 155-158.

Johnson-Laird, P.N. (1988). *The computer and the mind: an introduction to cognitive science*. Cambridge MA: Harvard University Press.

Jones, B.M. (2004). *Re-conceptualising the contingencies of reinforcement in matching-to-sample tasks*. Paper presented at the meeting of the Association for Behavior Analysis, Boston, MA.

Kazdin, A.E. (1982). *Single-case research designs*. New York: Oxford.

Lowenkron, B. (1984). Coding responses and the generalization of matching to sample in children. *Journal of the Experimental Analysis of Behavior, 42,* 1-18.

Lowenkron, B. (1988). Generalization of delayed identity matching in retarded children. *Journal of the Experimental Analysis of Behavior, 50,* 163-172.

Mackay, H.A. (1991). Conditional stimulus control. In I.H. Iversen & K.A. Lattal (Eds.), *Experimental analysis of behavior: part 1* (pp. 301-350). New York: Elsevier.

Mahadevan, R., Malone, J.C., & Bailey, J. (2002). Radical behaviorism and exceptional memory phenomena. *Behavior and Philosophy, 30,* 1-13.

Malott, R.M., & Suarez, E.T. (2003). *Principles of Behavior, 5th Edition*. Upper Saddle River NJ: Prentice Hall.

Marr, M.J. (1984). Conceptual approaches and issues. *Journal of the Experimental Analysis of Behavior, 42*, 353-362.

Mayer, R.E. (2003). Memory and information processes. In W.M. Reynolds & G.E. Miller (Eds.) *Handbook of psychology: Educational psychology* (pp. 47-57). New York: John Wiley & Sons.

Merle, P.G., Bushnell, P.J., Maurissen, J.P.J., Wenger, G.R., Buccafusco, J. J., Chelonis, J. J., & Eliot, R. (1998). Symposium overview: The use of delayed matching-to-sample procedures in studies of short-term memory in animals and humans. *Neurotoxicology and Teratology, 20*, 493-502.

Miller, L. (1988). Behaviorism and the new science of cognition. *Psychological Record, 38*, 3-18.

Nilsson, L-G. (1979). Functions of memory. In L-G. Nilsson (Ed.), *Perspectives on memory research* (pp. 3-15). Hillsdale, NJ: Lawrence Erlbaum Associates.

Palmer, D.C. (1991). A behavioral interpretation of memory. In L.J. Hayes & P.N. Chase (Eds.), *Dialogues on verbal behavior* (pp. 261-279). Reno, NV: Context Press.

Parsons, J.A. (1976). Conditioning precurrent (problem solving) behavior of children. *Revista Mexicana de Analisis de la Conducta, 2*, 190-206.

Parsons, J.A., Taylor, D.C. & Joyce, T.M. (1981). Precurrent self-prompting operants in children: Remembering. *Journal of the Experimental Analysis of Behavior, 36*, 253-266.

Polson, D.A.D. & Parson, J.A. (1994). Precurrent contingencies: Behavior reinforced by altering reinforcement probability for other behavior. *Journal of the Experimental Analysis of Behavior, 61*, 427-439.

Saunders, K.J. & Williams, D.C. (1998). Stimulus control procedures. In K.A. Lattal, & M. Perone (Eds.), *Handbook of research methods in human operant behavior* (pp. 193-228). New York: Plenum.

Sargisson, R.J., & White, K.G. (2001). Generalization of delayed matching to sample following training at different delays. *Journal of the Experimental Analysis of Behavior, 75*, 1-14.

Sidener, D.W. (2003, May). *Coding responses and generalization of matching to sample in children: A direct replication.* Paper presented at the meeting of the Association for Behavior Analysis, San Francisco, CA.

Skinner, B.F. (1953). *Science and human behavior.* New York: Simon and Schuster.

Skinner, B.F. (1957). *Verbal behavior*. New York: Appleton-Century-Crofts.

Skinner, B.F. (1960). Pigeons in a pelican. *American Psychologist, 15,* 28-37.

Skinner, B.F. (1968). *The technology of teaching*. New York: Appleton-Century-Crofts.

Skinner, B.F. (1974). *About behaviorism*. New York: Alfred A. Knopf.

Skinner, B.F. (1987). Whatever happened to psychology as a science of behavior? *American Psychologist, 42*, 1-7.

Skinner, B.F. (1989). The origins of cognitive thought. *American Psychologist, 44*, 13-18.

Torgrud, L. J., & Holborn, S. W. (1989). Effectiveness and persistence of precurrent mediating behavior in delayed matching to sample and oddity matching with children. *Journal of the Experimental Analysis of Behavior,* 52, 181-191.

Tulving, E. (1979). Memory research: What kind of progress? In L-G. Nilsson (Ed.), *Perspectives on Memory Research* (pp. 19-34). Hillsdale, NJ: Lawrence Erlbaum Associates.

Watkins, M.J. (1990). Mediationism and the obfuscation of memory. *American Psychologist, 45*, 328-335.

Wixted, J.T. (1998). Remembering and forgetting. In K.A. Lattal, & M. Perone, (Eds.), *Handbook of research methods in human operant behavior* (pp. 263-289). New York: Plenum.