Effects of Reinforcer Density versus Reinforcement Schedule on Human Behavioral Momentum

By

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Abstract

The essential tenet of the behavioral momentum model (BMM) is that relative response rate decreases less in the face of disruption when maintained by a higher reinforcer density. Empirical support exists based on both response-dependent and response-independent reinforcement. In the present study the BMM was tested with college students in 4 multi-element experiments, each using 2 reinforcement schedules and a disrupter. Participants performed a categorical sort (by orientation) of triangles on a computer monitor. Sorting response rates were disrupted by a concurrent task, pressing the keyboard "T" key whenever 2 displayed changing numbers were equal. Initial training established fast (under VR 4) and slow (under DRL 5-s) sorting rates, and provided practice with the disrupting task. In Experiment 1 DRL 5-s provided higher reinforcer density, while in Experiment 2 VR 4 did. In Experiment 3 the higher total reinforcer density was achieved by adding VT 6-s to DRL 5-s while in Experiment 4 it was achieved by adding VT 12-s to VR 4. In all 4 experiments, sorting rate decreased with introduction of the disrupter. In Experiments 1 and 3, relative sorting rate decreased less under DRL based schedule (greater reinforcer density), supporting the BMM. However, in Experiments 2 and 4, relative sorting also decreased less under DRL (lower reinforcer density), contrary to the BMM prediction. Taken together, these data show greater relative resistance to change under DRL (versus VR), independent of reinforcer density. Thus, contrary to the BMM, the nature of the reinforcement schedule seemed to be the principal factor determining behavioral momentum.

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The Behavioral Momentum Model

The behavioral momentum model (BMM) is a behavioral dynamic model. Behavioral dynamic models are metaphorical extensions of the dynamics of simple physical systems, and are intended to help uncover regular behavioral relations (Marr, 1992). For example, the relation between response rate and reinforcement schedule is described in the Matching Law (i.e., response rate is positively related to reinforcement rate). Ideally these relations can be described mathematically.

The BMM deals with the resistance of an established response rate to change. The factors considered in the BMM are response rate, reinforcer density (e.g., number of food pellets delivered/min), discriminative stimuli, reinforcement schedules, and resistance to change (response rate resistance to disruption). Nevin, Mandel, and Atak (1983) proposed the BMM which was supported in subsequent research (e.g., Nevin, Smith, & Roberts, 1987). The BMM central hypotheses is that resistance to change in response rate is positively related to reinforcer density. The behavioral terms used (including reinforcement schedules) are defined more completely in Appendix A, which also contains a discussion of related behavioral concepts.

Nevin, Mandel, and Atak (1983) framed their behavioral momentum model (BMM) in terms of an analogy to Newton's second law of motion. They see a metaphorical correspondence between resistance to change in response rate in behavioral dynamics and physical momentum in Newtonian dynamics. In the current research I tested the BMM in four experiments.

BMM Operations and Constructs

Newton's second law of motion states that an object's change in velocity is directly proportional to the applied force and inversely proportional to the object's mass (Newton, 1687/1952). The analogous BMM statement is that decrease in relative response rate is positively related to degree of disruption and negatively related to reinforcer density (reinforcers/min). BMM terms are discussed below.

Disrupting operations. In BMM research, a disrupting manipulation (disrupter) produces a decrease in response rate, and is considered to be a behavioral force. Three general examples of disrupters are: (a) reduction in reinforcer density, (b) satiation, and (c) distraction by alternative stimuli and/or competition with alternative behaviors.

Relative response rate. The use of relative response rates allows comparison of resistance to disruption across reinforcement schedules when response rates differ. For each schedule, relative rate is the ratio of disrupted response rate to non-disrupted baseline (BL) rate. Hence it is relative rather than absolute resistance to change that is compared between schedules. Relative response rate can be considered to be behavioral velocity.

Resistance to change. When a behavior is disrupted, if it maintains 80% of its BL (undisrupted) response rate, then it displays more resistance to change than if it were to maintain only 50%. Thus relative response rates are a measure of a behavior's resistance to change (behavioral momentum). This resistance to change of a discriminated operant is analogous to an object's physical momentum.

Discriminated operant. A discriminated operant is response class under the control of an antecedent stimulus (discriminative stimulus, or S^D) and reinforcement (see Appendix A). The discriminated operant is the behavioral "object" that has behavioral velocity (relative response rate), that is influenced by a behavioral force (disrupter), and that displays resistance to change in relative rate. The BMM references behavioral mass (see below), and states that it is positively related to its resistance to change.

The BMM Prediction

Nevin, Mandel, and Atak, (1983) and Nevin (1984) stated the basic tenet of the BMM; that is, when comparing relative rates of the same behavior under two reinforcement schedules, the relative rate would be more resistant to change under the schedule that delivers the greater reinforcer density. Thus resistance to change is a comparative rather than an absolute measure.

To parallel Newton's second law of motion, the BMM property can be restated as: relative change in behavioral velocity (relative response rate) is a negative function of behavioral mass (reinforcer density) and a positive function of magnitude of the behavioral force (disrupter).

The Pavlovian Contingency

Nevin (1984) and Nevin et al (1990) assert that resistance to change is based on total reinforcer density delivered in the presence of the discriminative stimulus (S^D). This stimulus-dependent reinforcement includes both response-independent and response-dependent reinforcement. Nevin calls the relation between discriminative stimulus (S^D) and reinforcement the "Pavlovian" contingency. Thus, according to the BMM, resistance to change is positively related to total reinforcer density in the presence of the S^D, rather than only to the response-dependent reinforcer density. This implies an equivalence of concomitant response-dependent and response-independent reinforcement in the determination of behavioral momentum, although response-dependent reinforcement is necessary for establishing the behavior initially.

However, in a different research paradigm (non-multiple schedule experiments), Lattal and Abreu-Rodrigues (1997) showed that the ratio of response independent to response-dependent reinforcement can affect some behavioral patterns (e.g., decrease in response rate). This result has not been evident in BMM steady-state multiple schedule experiments.

Matching

This BMM property is a "matching" property, with resistance to change positively related to (i.e., "matching") total reinforcer density. In partial contrast, another behavioral dynamic property, the Matching Law, states that response rate (not resistance) is positively related to (matches) response-contingent reinforcer density. Nevin (1992) stated that the BMM and the matching law describe distinct behavioral properties, and that response rate and resistance to change are independent properties. In contrast Killeen and Hall (2001) see both properties as factors positively related to the more general construct of response strength.

Behavioral Momentum Research

The initial BMM studies (e.g., Nevin et al., 1983; Nevin e al., 1987) used multiple schedule research designs and variable interval (VI) schedules, with pigeons as subjects. The disrupters used were pre-feeding and extinction. Less frequently, other interval and ratio schedules also have been employed. Research data has supported the BMM prediction with three species: pigeons, rats, and humans. The data providing the strongest support for the BMM is based on research with pigeons using VI schedules. In fact some of this pigeon-VI research has yielded mathematical relations between reinforcer densities, relative response rates, and degree of disruption (see Nevin et al., 1983). No other BMM results have has reached this level of mathematical clarity.

BMM and Humans

The value of a behavioral model depends on the degree to that it has been tested in varying conditions, including with different species, experimental manipulations, and research designs (Sidman, 1960). Particularly important is the degree to which a model can be generalized to human behavior. In fact a large part of the value of animal behavioral research depends on the insights it provides into human behavior (Lattal, 2001). However human operant research has a number of differences from animal research (Lattal & Perone, 1998a, Pilgrim, 1998). These include considerations that limit procedures used, time taken to establish behaviors, and how effectively outside influences (including prior learning) can be controlled. Also humans are different from animals in that humans use language extensively. This latter difference allows some efficiency of experimental technique through use of instruction and prompts. Human language also can alter sensitivity to contingencies, and thus can affect resistance to behavioral change (Madden et al., 1998; Torgrud and Holborn, 1990, Kollins et al. 1997).

Typical BMM Research Paradigm

BMM research has used several types of disruption and various resistance to change measures. Often resistance to change is measured in terms of relative response rates (relative to BL rate). Behavioral persistence also can be measured in terms of the conditions where responding ceases (e.g., number of sessions to extinction). Often used disrupters and their corresponding resistance measures are listed in Table 1. BMM researchers have used all of the disrupters and the resistance measures mentioned in Table 1.

Resistance to change studies with relative rate or sessions to extinction as resistance measures have provided the strongest support for the BMM, largely with multiple VI schedules. Examples supporting the BMM are: Nevin et al. (1983, pigeons), Mace et al. (1990, humans), Nevin et al. (1990, pigeons), Mauro and Mace (1996, rats), Plaud and Gaither (1997, humans), and Cohen (1998, pigeons).

Experimental Design Variations

BMM experimental designs have included simple schedules, multiple schedules, and concurrent chains. Variations in VI schedules have included reinforcer delay, reinforcer value (e.g. number of food pellets), and nature of the

Table 1.
Disrupters and Resistance Measures

Disrupters	Resistance to change measure
Pre-feeding: response-independent food is provided with no S^D before experimental trials (e.g., Nevin et l., 1983)	Disrupted response rates relative to BL rate
Reinforcer rate shift: reinforcer density is decreased (e.g., Plaud & Gaither, 1996)	Disrupted response rates relative to BL rate
Concurrent distracting stimulus (CDS): a stimulus is presented which distracts participants from the main behavior (e.g., Mace et al., 1990)	Disrupted response rates relative to BL rate
Extinction (sessions with no reinforcers): (e.g., Nevin et l., 1983)	Number of extinction sessions to response cessation
Progressive ratio (PR) schedule: the number of responses per reinforcement increases with each successive reinforcement (e.g., Lattal et al., 1998)	Last (highest) ratio value before responding ceases for a predetermined time interval

reinforcer (e.g., type of food). Galbicka and Kessel (2000) suggested that this predominant use of VI schedules has limited the BMM's generality, and recommended that BMM research would benefit from a wider scope of reinforcement schedules. Although some BMM research included ratio schedules, none of the BMM focused research has involved the use of differential reinforcement of low response rate (DRL) schedules. However Nevin et al. (2001) did describe some previous non-BMM studies that introduced slow pacing requirements through tandem schedules with a DRL schedule as the second (final) link. These studies used rats and pigeons, but not humans, as experimental participants.

Ratio Versus Interval Schedules

Lattal, Reilly, and Kohn (1998) investigated how responding in pigeons differed between progressive ratio (PR) and yoked interval schedules with equivalent reinforcer densities. They suggested that interval schedules generate greater behavioral momentum than do ratio schedules with equal reinforcer densities. In like vein, Nevin et al. (2001) found that resistance to change under VR schedules was less than that under VI schedules of equivalent reinforcer density, and also found that pigeons preferred VI schedules to VR schedules. These results suggest that the nature of a schedule or response rate is a salient factor. Nevin et al. argue that response rate under schedules with the highest response rate (e.g., VR) are more susceptible to disruption than relative rates under schedules with lower response rates (e.g., VI). This is discussed in more detail in Appendix B. A remaining question is under which circumstances other factors could be related to resistance to change. Possible factors include the nature of reinforcement schedules, response rate, verbal behavior, as well as reinforcer density.

Simple Schedules

Cohen et al. (1993) and Cohen (1998) found that reinforcer density is positively related to resistance to change in multiple schedules but not in simple schedules. In contrast, Nevin (1988) found support for the BMM with simple schedules in a review of data from previous studies. Overall it seems uncertain as to what degree and in what circumstances the BMM fits simple schedules.

Aptness of the Behavioral Momentum Metaphor

The BMM metaphorical relation to Newton's second law of motion seems most clear when change in relative response rate is the resistance measure. However some of the support for the BMM relies on extinction as the disrupter, and the different resistance measure, that is, the number of experimental sessions to response cessation. Also Harper and McClean, (1992) and McClean and Blampied (1995) have suggested that typical disrupters (e.g., extinction, pre-feeding) change the "object" (discriminated operant) on which behavioral forces act, thus straining the BMM metaphorical connection to Newton's second law. They call such disrupters "internal", and recommend instead the use of "external" disrupters that do not alter the "object" upon which the disrupter acts.

Because reinforcement schedules typically establish and maintain responding, some behavioral dynamic models consider them to be behavioral forces (Marr, 1992). In contrast the BMM considers the disrupter to be the behavioral force that lowers response rate. Houlihan and Brandon (1996) believe that the reinforcement schedules which maintain responding also should be considered as behavioral forces in the BMM. In addition Houlihan and Brandon consider response cost to be an analog of friction or air resistance, and thus to be another force affecting response rate.

With this expanded definition of behavioral force, changes in response rate would be due to the interaction of several "forces": the maintaining schedule, disruption, and response cost. This conception of multiple behavioral forces would provide a more complete metaphorical connection to Newton's laws. Also it would openly acknowledge the contribution of the several factors influencing response rate. This extension also could be applied to response rate increases or decreases that take place during acquisition of steady-state responding.

Unexplored Questions about the BMM

It seems that the BMM has strong support from many multiple schedule studies. However several areas remain largely unexplored: (a) the relative role of schedule effects, (b) how well the BMM fits other species, (c) its applicability to simple schedules, and (d) the utility of the BMM in non-steady state situations (where rate of change rather than degree of change is investigated).

The areas raise questions as to what degree BMM predictions can be generalized, in terms both of non-VI schedules and of species. While some exploration of these areas has already been conducted, the conditions in which the BMM is useful have not been completely delineated. In the present research I explored some of these limits, specifically with non-VI schedules, clearly different response rates, an external disrupter, and human participants.

An Example Study Related to the Current Research

Some BMM studies using human participants have supported the BMM (e.g., Cohen, 1996; Plaud, Gaither, & Lawrence, 1997; Mace et al., 1990). The Mace et al. study is described below because the present study was based on it.

Nature of the Experiment

Mace et al. (1990) tested the BMM using two human adults with developmental delays. The behavior was a categorical sort of plastic cutlery (e.g., spoon with spoons, knife with knives, fork with forks). The reinforcer was the participant's choice of coffee or popcorn. The discriminative stimulus (S^D) was the color of the cutlery (green, red). The disrupter was a television concurrently playing a music video. Mace et al. called this a concurrent distracting stimulus (CDS). Watching the music video is both a concurrent behavior and also an alternate source of reinforcement (entertainment). This disrupter is external because it does not directly alter the relation among behavior, S^D, and reinforcer.

Mace e al.'s experimental design consisted of alternating conditions (changing between baseline and disruption) using two VI schedules. The experiment was in two parts: Part 1 used only response-dependent reinforcement, and Part 2 used a combination of response-dependent and response-independent reinforcement.

Reinforcement Schedules

In Part 1 Mace et al. tested the BMM with response-dependent reinforcement, using VI 60-s and VI 240-s schedules. The VI 60-s has approximately 4 times the reinforcer density of VI 240-s, so the BMM predicts that resistance should be greater under VI 60-s.

In Part 2 they tested the BMM with a combination of concomitant response-dependent (VI) and response-independent variable time (VT) reinforcement. The schedules used were VI 60-s and VI 60-s + VT 30-s. The VI 60-s + VT 30-s reinforcer density was approximately 3 times that of VI 60-s alone.

Results

Mace et al.'s results showed that, for both participants and in both Parts 1 and 2, there was less relative change under the schedule with the greater reinforcer density. Hence relative sorting rate resistance to change was greater under the schedule with the greater reinforcer density, thus supporting the BMM. Individual differences between participants in terms of both response rates and resistance were evident, but the data consistently supported the BMM .

General Method

The present study was a systematic replication of that of Mace et al. (1990). Like Mace et al., participants were human, sorting was the principal behavior, and the disrupter used a CDS. Part A (Experiments 1 and 2) tested the BMM with response-dependent reinforcement, generalizing Mace et al.'s (1990) Part 1. Part B (Experiments 3 and 4) tested the BMM with a combination of response-dependent and response-independent reinforcement, generalizing Mace et al.'s Part 2.

Important variations include computerized administration, DRL and VR reinforcement schedules, reinforcer, disrupter, setting, and participant population. Slow response rates obtained under DRL schedules constitute a marked change from the higher rates under VI schedules used in BMM studies. Response rates produced under VR schedules are typically somewhat higher than those produced under VI schedules.

Current Research Design Features

The three principal manipulations were: (a) the use of two different reinforcement schedules (DRL and VR), (b) the use of disruption versus baseline (no disruption), and (c) the inclusion of response-independent reinforcement in Part B. Each experiment was of multi-element design, replicated across participants. Multi-element designs are efficient single-organism experimental designs for investigating effects of several manipulations in one experiment (Sidman, 1960, pp. 326-330). The common features of the 4 experiments are described below and are summarized in Table 2. The designs of all four experiments differ only in terms of point densities and the introduction of VT response-independent reinforcers in Part B.

Participants

Participants were recruited from University of Manitoba introductory psychology classes. They participated to earn experimental credits towards their course grade. Both information presented to prospective participants and the participant informed consent form are shown in Appendix F. Each student participated in only 1 of the 4 experiments.

Apparatus and Setting

Each participant worked at a microcomputer running the experimental administration program. The microcomputers were located in the University of

Table 2

Experiments 1, 2, 3, and 4 Common Features

Feature	Description
Design	Multi-element, single organism, alternating conditions, computer administered
Behavior	Sorting triangles on a computer screen
Reinforcer	Game points to be exchanged for ticket draws for small sums of money
Reinforcement schedules	DRL 5-s and VR 4 (with response independent VT reinforcement added in Part B). The number of points delivered per reinforcement was fixed for each experiment, but differed between schedules.
S^D	For each reinforcement schedule, a Lime or Fuchsia hue was used to color the triangles, targets, screen border, and post element point total
Disrupter	CDS consisted of a pair of changing 5 digit numbers. The associated concurrent distracting task (CDT) consisted of pressing the "T" key when the CDS numbers were equal.
Elements	Each element combined one of the two reinforcement schedules and either BL (no disrupter) or one of the two CDS levels
Experimental sessions	There were 3 sessions, each consisting of 2 trials. In each session, one trial used one CDS level while the other used the second CDS level. Each trial was a sequence of eight 3 minute elements (trial duration approximately 24 minutes).

Manitoba Psychology Department computer laboratory. There were 7 rows of computers, with 7 per row. Participants were distributed regularly with a maximum of three participants to a row, and worked at their computers concurrently.

The administration program managed both the training and experimental trials, and also recorded experimental data. For each participant, data collected for each element included response rates, points earned, and the degree of compliance with the distracting task.

Experimental Behavior

The principal experimental behavior was a categorical sort by orientation of the triangular symbols ▽, △, ▷, and ◁. Previous computerized BMM research with humans involved pressing keys on computer keyboard, whereas a computerized sorting behavior is an analog of a more natural human behavior, such as sorting plastic cutlery in Mace et al. (1990).

In order to sort a triangle, a participant would drag it from its position at the bottom half of the screen to its matching target triangle. However as the triangle approached the target, the target would begin moving away, although it could be trapped in a corner. When the triangle contacted the target, both disappeared, the target reappeared in its original location, and the triangle reappeared in a random location in the bottom half of the screen.

Nature of the Reinforcer

As in Plaud, Gaither, and Lawrence (1997), different point densities were achieved by adjusting the number of points delivered per reinforcement. The reinforcers were game points which were exchanged for lottery tickets, with draws at the end of the last experimental session, one ticket draw for each 1000 points earned. These tickets were then exchanged for small cash prizes. The value of a draw ranged from $0.05 to $20.00, with an expected value of $0.437. Such ongoing "bonus" reinforcement serves to maintain human operant performance during an experiment (Pilgrim, 1998).

Point total display. When points from sorting were available, an underlined blinking message appeared at the bottom of the screen, indicating that these points were available. The participant accepted these points by pressing the space bar. Then the trial sorting-related point total (top left of screen) was incremented, blinked once in bold larger digits, and then returned to its original appearance. Continued sorting was prevented until the earned points were accepted.

Inter-element messages. After each 3-minute experimental element, during the pause before the next element, a message (in the previous S^D hue) was displayed indicating how many points had been earned during that element, as well as indicating what that hue was. The message also told what the hue of the next element would be.

Reinforcement Procedures

The two response-dependent reinforcement schedules used were VR 4 and DRL 5-s, and the S^D hues were fuchsia and lime (balanced across participants in each experiment). These two response-dependent reinforcement schedules functioned as follows:

1. Under the DRL 5-s schedule, a reinforcement occurred only if, since the last DRL 5-s delivered reinforcer, both of two conditions were met:

(a) 5 s or more had elapsed, and (b) no other sort had been completed. If either condition were not met then no reinforcer was delivered and the DRL 5-s timer was reset to 5 s. In this case, a pop-up message was displayed indicating that the sorting response was too early.

2. Under the VR 4 schedule, a random ratio parameter was uniformly distributed among the values 2, 3, 4, 5, and 6, and reinforcement occurred after that number of triangles was sorted.

The reinforcement schedule parameter values were chosen so that the schedules would deliver reinforcement several times per 3-minute element. The number of points delivered per reinforcement were chosen to make the two schedule's point densities markedly different.

Disrupting Operation

Disruption combined a concurrent distracting stimulus (CDS) with an associated concurrent distracting task (CDT). Disruption did not interfere directly with the sorting task other than requiring part of a participant's attention. Because this disrupter did not alter the reinforcement contingencies that maintained sorting, it acted as an external disrupter rather than as a more typically used internal disrupter.

Nature of the CDS. The CDS consisted of two changing five digit numbers displayed at the top centre of the computer screen. These numbers changed every 1.13s for CDS level 1 (CDS1), and every 0.63s for CDS level 2 (CDS2). The two CDS numbers became equal on average every 5.0 s. No CDS was displayed during baseline.

Nature of the CDT. The CDT consisted of pressing the keyboard 'T' key each time the two CDS numbers were equal. The actual windows of opportunity for a 'T' press response to be accepted were incremented by 0.20s to compensate for "T" press latency. The program did not accept "T" presses outside those intervals and did not accept more than one "T" press per interval.

Points contingent on the CDT. One game point was delivered each time the participant correctly pressed the "T" key. These CDT based points incremented a separate "T" press total points display for the trial, with no other visible change and no need to press the space bar.

Disruption Manipulation Check

One step in checking the effectiveness of the disrupter was to ascertain the degree to which the participant was attending to the CDS and performing the CDT. The 'T' pressing performance (TPP) measure was intended to fulfill this purpose. For each element, the TPP is a proportion obtained by dividing the number of accepted "T" key presses by of the number of times the two CDS numbers were equal, expressed as a percentage.

The TPP served as a CDT manipulation check. If TPP dropped near zero, it indicated that the participant likely was ignoring the CDT. In that case the CDS and CDT probably were not acting as intended. Based on the observed relation between TPP and response rate disruption in Slivinski (2001), a lower mean TPP limit of 20% was used as a cutoff value for CDT compliance. Of course the ultimate check of a distraction effect is whether there is indeed a decrease in response rate.

Common Features of the Experimental Design

Each of the four experiments was a single organism multi-element alternating conditions design replicated across participants. Each experiment consisted of three experimental sessions, each on a separate day. Each session contained two trials, one using CDS1 and the other using CDS2. Each trial was of 24 minutes duration, with 8 elements of 3 minutes duration each. BL and disruption were alternated in each experimental trial.

Elements

Because the two independent variables in the multi-element design were reinforcement schedule (2 schedules) and CDS level (BL, CDS1, or CDS2), there were 6 distinct elements for each experiment. Because each trial used only one CDS level, there were 4 distinct elements for each trial.

Element Sequences

In each trial, the first 4 elements of the sequence of 8 would be: (a) two elements using BL (each with a different schedule), followed by (b) two elements using the trial's CDS level (each with a different schedule). The next 4 elements of the trial would be similar, but balanced for schedule order.

Training Sessions

Training sessions preceded the experiment proper in all experiments. The training was entirely computer administered. Training consisted of text instructions followed by task practice, along with on screen information, pop-up prompts, and between element summaries. Participants developed familiarity with S^D hues, sorting, point collection, VR 4 and DRL 5-s reinforcement schedules, and with the

CDS and CDT. Examples of instruction and feed-back screens are shown in Appendix G.

Hue Perception Test

A computer program was used to test whether participants could discriminate between colors by naming them. The program presented a squares of a given hue a on the computer monitor, and the experimenter asked the participant to name the hue. Eight hues were presented in random order: lime, fuchsia, grey, red, green, purple, yellow, and blue, with particular attention to fuchsia and lime (the two S^D's used).

Questionnaire

A questionnaire was administered to sample participants' verbal behaviors related to their experimental behaviors. Part 1 of the questionnaire consisted of multiple-choice questions regarding which hue was associated with greater point density and with the greater number of points per reinforcement. Parts 2 and 3 of the questionnaire used open-ended questions to sample participants' verbal behavior related to the effects of the CDS and participant rules or strategies that they might have used during the experiment. The questionnaire is presented in Appendix D.

Common Experimental Procedure

Participants were assigned computers, and pairing of S^D hue with schedule was balanced across participants. The computerized hue perception test was administered. General instructions were given at the beginning of the first session concerning meeting times, break time between trials, points accumulated for money draws, and following instructions on the computer screen. Then participants began the training trials which introduced the schedules, sorting, CDS, and points earned, allowed practice, and gave instruction and feed-back.

The three experimental sessions were run on the next 3 days. Part 1 of the questionnaire was administered after the first experimental session, and all parts of the questionnaire were administered after the third (last) experimental session. Also after the third experimental session the experiment's purpose and anticipated results were explained to the participants, and then participants drew tickets for prizes and received cash prizes.

Part A

The two experiments in Part A were systematic replications of Mace et al.'s (1990) Part 1, but used DRL 5-s and VR 4 response-dependent schedules instead of VI. Both Part A experiments were conducted simultaneously, with Experiment 1 participants interspersed with those from Experiment 2. The difference between Experiments 1 and 2 was that in Experiment 1 reinforcer density was higher under DRL 5-s (slower response rate), while in Experiment 2, reinforcer density was higher under VR 4 (faster response rate). In this manner effects of reinforcer density were separated from effects of reinforcement schedule.

Experiment 1

Method

Experiment 1 adhered to the common method described above and summarized in Table 2.

Participants

The participants were 2 males and 2 females, with ages ranging from 20 to 24 years (M= 22.0 years). Participants' gender and age are shown in Table 3.

Procedure

Experiment 1 followed the experimental procedure described above (p. 20).

Reinforcement schedules. The two reinforcement schedules were VR 4 delivering 4 points per reinforcement and DRL 5-s delivering 6 points per reinforcement. These point values were chosen so that the point density under DRL 5-s would be greater than that under VR 4.

Experiment 1 Results

Verbal Discrimination

In the hue perception test, all participants correctly verbally discriminated between hues. In Part 1 of the questionnaire, all participants verbally discriminated between reinforcement schedules by correctly matching the hue name (lime or fuchsia) with more (or less) points delivered and with faster (or slower) sorting rate.

BL Point Densities

Mean BL point densities are shown in Table 3 under heading "BL point density ". For Aby, point density was 17.8 points/min under VR 4, and 48.4 points/min under DRL 5-s. This shows a much higher point density under DRL 5-s than under VR 4. For all participants, we see that the DRL 5-s point density is consistently greater than VR 4 point density by a multiple of approximately 2 or more. Thus point densities were markedly different between schedules, as required to test the BMM.

Table 3

Experiment 1 Mean Values across Sessions

Participant			Reinforcement Schedules[2]	BL point density[3]	BL rate[4]	Disrupted rate[4]	Relative rate (%)[5]	TPP (%)[6]
Name[1]	M/F	Age						
Aby	F	20	VR 4	17.8	18.8	13.4	71.5	41.1
			DRL 5-s	48.4	8.8	7.4	83.8	50.9
Ace	M	24	VR 4	20.4	20.8	15.7	75.3	56.4
			DRL 5-s	52.9	9.6	8.3	80.1	61.6
Ada	F	20	VR 4	21.6	22.7	14.9	65.6	75.4
			DRL 5-s	50.2	9.2	6.6	71.7	80.5
Arn	M	24	VR 4	28.1	28.5	20.8	72.9	66.7
			DRL 5-s	55.8	10.1	7.9	77.8	74.1

[1] These are not the participants' real names.

[2] Four points per reinforcer were delivered under VR 4, while six points per reinforcer were delivered under DRL 5-s

[3] BL point density is measured in points delivered per minute

[4] Rate is measured in responses per minute

[5] Relative rate represents Disrupted Rate as a percentage of BL rate

[6] TPP represents the percentage of intervals that the CDS numbers were equal during which the "T" key was pressed

Response Rates

BL sorting rates. For Experiment 1, mean BL sorting rates are shown in Table 3, under heading “BL rate”. Looking at all participants’ BL sorting rates, we see that under VR 4 they ranged from 18.8 responses/min for Aby up to 28.5 for Arn. In contrast, DRL 5-s mean BL sorting rates ranged from 8.8 responses/min for Aby up to 10.1 for Arn. For each participant the VR 4 mean response rate was substantially higher than the DRL 5-s rate (in keeping with the nature of these reinforcement schedules).

Disrupted Sorting Rates. Mean disrupted sorting rates (averaged across CDS levels) are shown in Table 3, under the heading “Disrupted rate”. Averaging across CDS levels provided more regular data and also has the advantage of making comparisons of resistance across schedules simpler (see Appendix C). For all participants disrupted rates were lower than BL under both schedules.

Mean relative rates. Relative rate values are shown under heading “Relative rate (%)”. These relative rate values are the percentage that the disrupted rate is of BL rate. Relative rate values under VR 4 are consistently lower than those under DRL 5-s.

TPP Manipulation Check

The TPP measure gives the percentage of “T” press opportunities that the participant correctly exploits. For Experiment 1, TPP values are shown in Table 3 under the heading “TPP (%)”. Looking at all participants’ TPP data , we can see that VR 4 mean TPP values range from 75.4% (Ada) down to 41.1% (Aby). Under DRL 5-s they range from 80.5% (Ada) down to 50.9% (Aby). For all participants, the TPP under VR 4 is lower than that under DRL 5-s (where sorting demands were less). TPP data patterns somewhat parallel those of relative rate, that is, values are higher under DRL 5-s than under VR 4 for all participants.

Relative Rate as a Function of Reinforcement Schedule

Experiment 1 relative rates (disrupted) across the 3 sessions are shown in Figure 1. For each session the relative rate values are mean element values averaged across the session's two trials. Because VR 4 response rates increased across sessions, the session relative rates were calculated relative to session BL mean rates.

First consider Aby's graph. Her DRL 5-s plot is clearly higher than her VR 4 plot for all 3 sessions. This pattern is also evident for Ace and Ada, although in one session for each the difference between schedules is minimal. This pattern is most weakly evidenced for Arn, whose VT 4 value was higher in one session, while being lower for the other 2 sessions. Thus generally DRL-5s relative rates are higher than VR 4 relative rates.

Experiment 1 Discussion

The conditions needed to test the BMM were met for Experiment 1: (a) higher reinforcer density under DRL 5-s than under VR 4, and (b) the disrupter lowered response rates. In addition other design conditions were met: (a) compliance with the CDT, (b) verbal discrimination between schedules, and (c) greater response rates under VR 4 than under DRL 5-s.

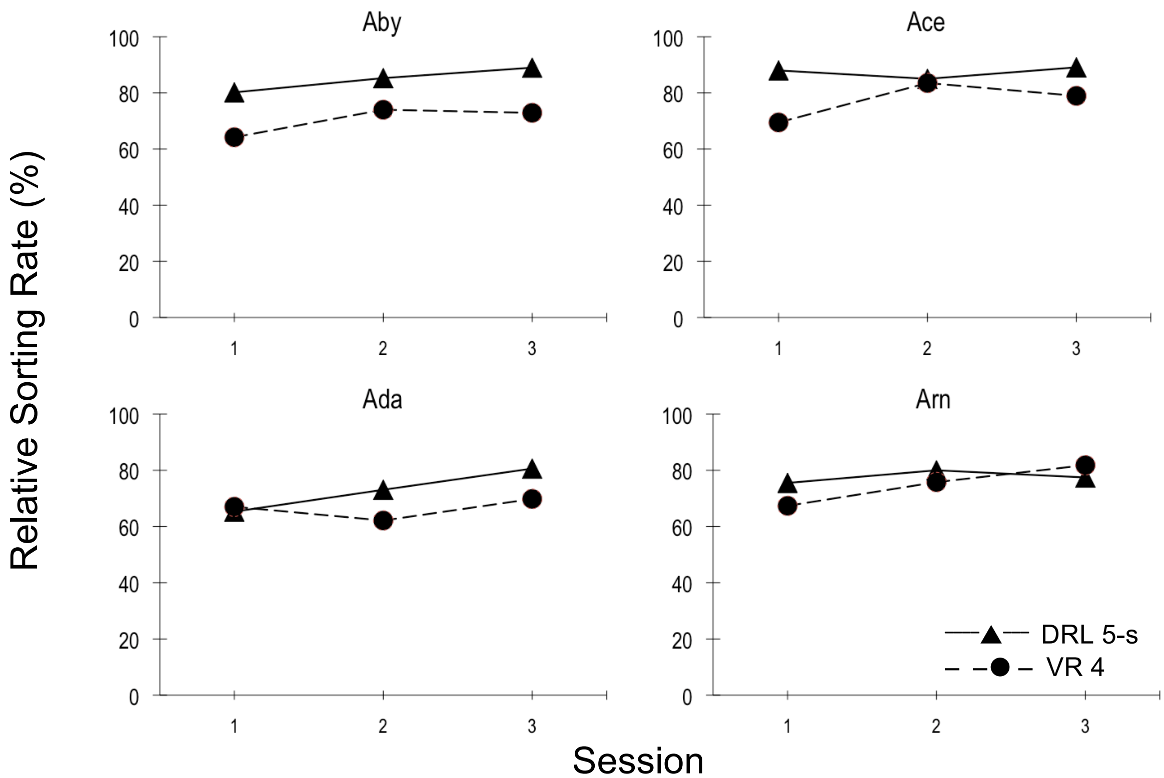

Figure 1. Experiment 1 relative sorting rates under VR 4 and DRL 5-s.

DRL 5-s was the schedule with higher relative rates across participants, so it was under DRL 5-s that resistance to change was greater. Because the schedule with higher point density (DRL 5-s) showed more resistance to change, Experiment 1 data supported the BMM hypotheses.

Experiment 2

Method

The Experiment 2 method was as described above and as summarized in Table 2.

Participants

Experiment 2 participants were 2 males and 2 females, with ages ranging from 23 to 40 years (M= 30 years). One participant, Bet, only attended two experimental sessions, being unable to attend the middle session due to an unanticipated commitment. Participants' gender and age are shown in Table 4.

Procedure

The Experiment 2 procedure also followed the common experimental procedure described above (p. 20).

Reinforcement schedules. The two reinforcement schedules were VR 4 delivering 12 points per reinforcement and DRL 5-s delivering 2 points per reinforcement. These point values were chosen so that the point density under VR 4 would be greater than under DRL 5-s.

Table 4

Experiment 2 Mean Values across Sessions

Participant			Schedules[2]	BL point density[3]	BL rate[4]	Disrupted rate[4]	Relative Rate (%)[5]	TPP (%)[6]
Name[1]	M/F	Age						
Bas	M	29	VR 4	79.6	26.8	16.2	60.3	62.7
			DRL 5-s	19.7	10.3	9.3	90.2	65.4
Bet	F	29	VR 4	58.5	20.8	13.4	64.6	68.4
			DRL 5-s	16.2	9.0	7.4	82.4	79.0
Bix	M	23	VR 4	69.5	22.3	18.4	82.7	42.9
			DRL 5-s	15.6	9.8	8.8	90.2	45.8
Bon	F	40	VR 4	33.5	11.5	6.6	57.6	22.8
			DRL 5-s	14.1	8.6	5.8	67.1	40.9

[1] These are not the participants' real names.

[2] VR 4 delivered twelve points per reinforcement, while DRL 5-s delivered two points per reinforcement

[3] BL point density is measured in points per minute

[4] Rate is measured in responses per minute

[5] Relative rate represents Disrupted rate as a percentage of BL rate

[6] TPP represents the percentage of intervals that the CDS numbers were equal during which the "T" key was pressed

Experiment 2 Results

Verbal Discrimination

All participants verbally discriminated between hues in the hue perception test. In questionnaire Part 1, all participants verbally discriminated between DRL 5-s and VR 4 by correctly matching the hue's name (lime or fuchsia) with more (or less) points delivered and with faster (or slower) sorting rate.

BL Point Densities

Mean BL densities are shown in Table 4 under the heading "BL Point density". For all Experiment 2 participants, VR 4 BL point densities were more than double those under DRL 5-s, and in fact, except for Bon, were more than triple those under DRL 5-s. Thus point densities were markedly different between schedules, as required to test the BMM.

Response Rates

BL sorting rates. For Experiment 2, mean BL sorting rates are shown in Table 4 under the "BL rate" heading. Under VR 4 these rates ranged from 26.8 responses/min for Bas down to 11.5 responses/min for Bon. Under DRL 5-s, rates ranged from 10.3 for Bas down to 8.6 for Bon. For each participant, the mean rate under VR 4 was substantially higher than that under DRL 5-s. In fact, except for Bon, VR 4 BL rates were more than double DRL 5-s BL rates.

Disrupted sorting rates. Mean disrupted sorting rates are shown in Table 4, under the heading "Disrupted rate". The disrupted rate values are lower than BL rates, showing that the disrupter functioned as designed. Also the VR 4 disrupted rates are higher than DRL 5-s disrupted rates for each participant.

Relative rates. Relative rates are shown under the heading “Relative rate. Relative rates under VR 4 were consistently much lower than those under DRL 5-s.

TPP Manipulation Check

Mean TPP values are shown for each participant in Table 4 under the heading “TPP (%)”. We can see that VR 4 TPP mean values range from 68.4% (Bet) down to 22.8% (Bon). Also DRL 5-s TPP values range from 79.0% (Bet) down to 40.9% (Bon). For each participant the TPP value was lower under VR 4 than under DRL 5s.

Relative Rate as a Function of Reinforcement Schedule

Experiment 2 relative sorting rates across the 3 sessions are shown in Figure 2. Consider Bas’s relative rate graph at the top left of Figure 2. His relative response rates under VR 4 are substantially lower than those under DRL 5-s in each session. This is also true for Bet to a lesser degree, although she could only participate in two sessions. This pattern of the DRL 5-s plot being higher than the VR 4 plot continues to a lesser degree for Bix and Bon. So in Experiment 2, relative rates are always higher under DRL 5-s than VR 4 for all participants.

Experiment 2 Discussion

The conditions required to test the BMM were met in Experiment 2: (a) higher reinforcer density under VR 4 than under DRL 5-s, and (b) the disrupter lowered response rates. In addition other conditions also were met: CDT compliance, verbal discrimination between schedules, and greater response rates under VR 4 than under DRL 5-s.

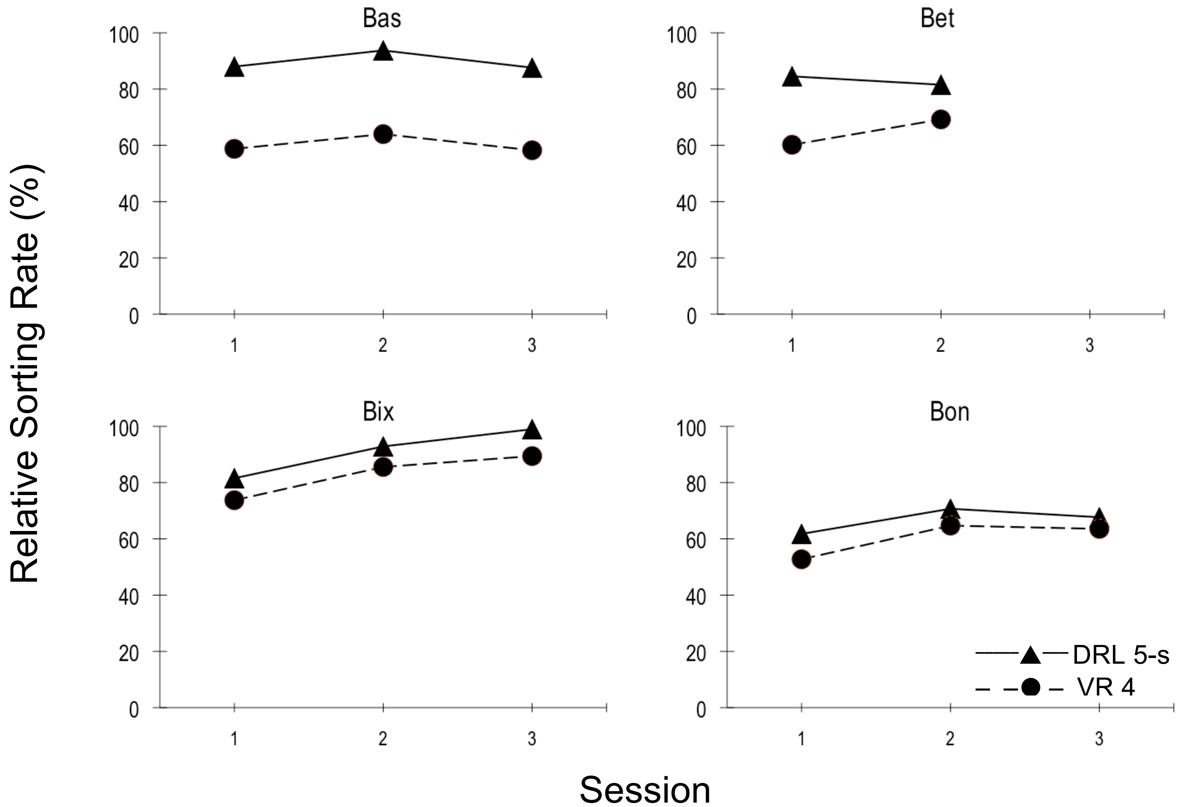

Figure 2. Experiment 2 relative sorting rates under VR 4 and DRL 5-s. Bet participated in only 2 sessions due to an unforeseen commitment.

In Experiment 2 the BMM prediction is that sorting resistance to change under VR 4 (higher point density) should be greater than under DRL 5-s. In terms of relative rates, the BMM prediction is that relative rates under VR 4 should be higher than under DRL 5-s. However Experiment 2 data revealed greater relative rates under DRL 5-s. Thus Experiment 2 data contradict the BMM hypotheses.

Part B

In Part B response-independent reinforcement was added to in one reinforcement schedule in each of Experiments 3 and 4. This generalized Mace et al.'s Part 2 test of the effects of the "Pavlovian" contingency on resistance to change of response rates. The two Part B experiments were conducted simultaneously. Because Part B is otherwise similar to Part A, Part B data may be able to shed light on the apparently contradictory evidence in Part A regarding the BMM.

Experiment 3

Method

Experiment 3 followed the general method as in Experiments 1 and 2 .

Participants

The participants were 3 males and 1 female (ages ranging from 20 to 37 years, M = 25.0 years). Participants' gender and age are shown in Table 5.

Procedure

The Experiment 3 procedure follows the common experimental procedure described above (p. 20).

Reinforcement schedules. The two reinforcement schedules were DRL 5-s + VT 6-s delivering 2 points per reinforcement, and VR 4 delivering 4 points per reinforcement. With the compound DRL 5-s + VT 6-s schedule, the DRL 5s (response-dependent) and VT 6-s (response-independent) parts delivered points independently and concurrently. Points from both response-dependent and response-independent contingencies were accumulated together. These schedules were designed so that DRL 5-s+ VT 6-s would provide a higher point density than VR 4 would.

Experiment 3 Results

Verbal Discrimination

All participants verbally discriminated between hues in the hue perception test. In questionnaire Part 1 all participants verbally discriminated between reinforcement schedules on the basis of hue name, point density, and response rate.

BL Point Densities

BL total point densities are shown in Table 5 under the heading "BL point density". The mean point densities were consistently higher under DRL 5-s + VT 6-s schedule than under VR 4, by factors ranging from 1.8:1 (Cob) down to 1.2:1 (Cat). Thus the point density ratios were less than in Experiments 1 and 2.

Response Rates

BL sorting rates. Mean BL sorting rates are shown in Table 5 under the heading "BL rate". As anticipated, sorting rates are consistently higher under VR 4 than under DRL 5-s + VT 6-s. Rates under VR 4 ranged from 29.2 response/min (Cat) down to 18.6 (Cob). Rates under DRL 5-s + VT 6-s ranged from 9.7 (Cec and Civ) down to 9.1 (Cob).

Table 5

Experiment 3 Mean Values across Sessions

Participant			Schedules[2]	BL point density[3]	BL rate[4]	Disrupted rate[4]	Relative rate (%)[5]	TPP (%)[6]
Name[1]	M/F	Age						
Cat	F	20	VR 4	29.2	29.2	22.5	77.1	75.1
			DRL 5-s+VT6-s	34.8	9.6	8.4	87.4	80.6
Cec	M	22	VR 4	22.9	23.1	17.3	75.0	58.6
			DRL 5-s+VT6-s	33.0	9.7	7.8	80.1	78.8
Civ	M	37	VR 4	23.0	23.3	19.1	82.0	65.6
			DRL 5-s+VT6-s	34.9	9.7	8.2	84.5	82.4
Cob	M	21	VR 4	18.6	18.6	16.5	88.8	31.8
			DRL 5-s+VT6-s	34.1	9.1	8.2	90.0	42.8

[1] These are not the participants' real names.

[2] VR 4 delivered four points per reinforcement, while DRL 5-s + VT 6-s delivered two points per reinforcement

[3] BL point density is measured in points per minute

[4] Rate is measured in responses per minute

[5] Relative rate represents Disrupted rate as a percentage of BL Rate

[6] TPP represents the percentage of intervals that the CDS numbers were equal during which the "T" key was pressed

Disrupted sorting rates. Mean disrupted sorting rates are shown in Table 5 under the heading "Disrupted rate". Looking at the disrupted rates, we see that they are all lower than BL rates, indicating that the disrupter functioned as designed. Also the VR 4 mean disrupted rates are consistently higher than DRL 5-s + VT 6-s rates.

Relative rates. Mean relative rates also are shown in Table 5 under the heading "Relative rate". Relative rates consistently are lower under VR 4 than under DRL 5-s + VT 6-s, although the difference is quite small for Civ and Cob.

TPP Manipulation Check

For Experiment 3, mean TPP values are shown in Table 5 under the heading "TPP". For each participant the TPP value under VR 4 was lower than that under DRL 5-s + VT 6-s, although the differences varied among participants.

Relative Rate as a Function of Reinforcement Schedule

Experiment 3 relative rates across sessions are shown in Figure 3. For Cat and Cec the DRL 5-s + VT 6-s relative rates were consistently greater than those under VR 4. However for Civ and Cob this difference is clear only for session 2. Also Civ's and Cob's overall mean relative rate values (from Table 5) were barely higher under DRL 5-s + VT 6-s than under VR 4. Thus DRL 5-s + VT 6-s relative rates were clearly greater than the VR 4 relative rates only for Cat and Cec, and the difference was ambiguous for Civ and Cob.

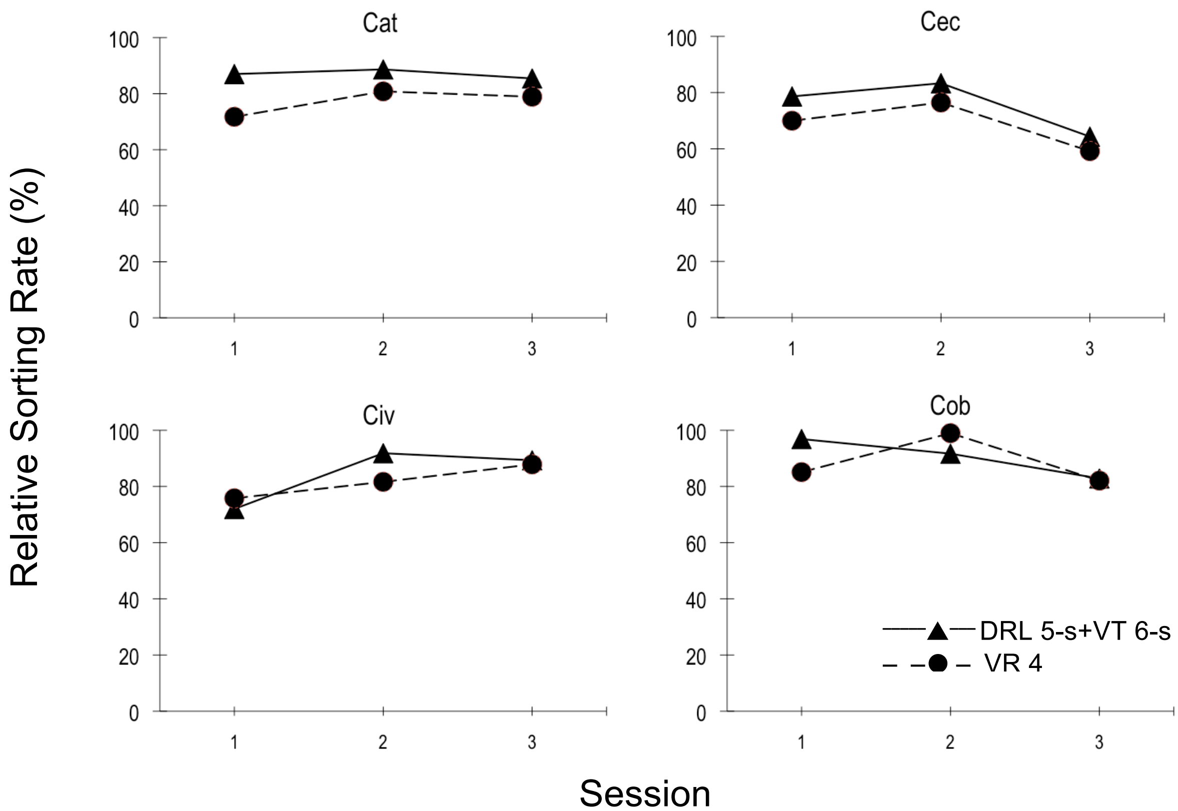

Figure 3. Experiment 3 relative sorting rates under DRL 5-s + VT 6-s and VR 4.

Experiment 3 Discussion

In Experiment 3 the conditions necessary for testing the BMM were met: (a) higher reinforcer density under DRL 5-s + VT 6-s than under VR 4, and (b) the disrupter lowered response rates. However the difference in point densities is not as evident as in previous experiments, and this might weaken the conditions for testing the BMM. Other design conditions also were met: (a) CDT compliance, (b) verbal discrimination between reinforcement schedules, and (c) greater response rates under VR 4 than under DRL 5-s.

In Experiment 3 the BMM prediction is that sorting resistance to change under DRL 5-s + VT 6-s should be greater than under VR 4 because DRL 5-s + VT 6-s has the greater point density. Thus the BMM prediction is that relative rates under DRL 5-s + VT 6-s should be higher than those under VR 4. This indeed was the case for 2 participants and ambiguous for the other 2 participants. Thus Experiment 3 data does support the BMM hypotheses, but less clearly than in Experiment 1.

Experiment 4

Method

Experiment 4 duplicates the general method as did the previous experiments.

Participants

Three male and two female students were recruited (ages ranged from 21 years to 23 years, M = 22.4 years). Participant’s gender and age are shown in Table 6.

Procedure

The Experiment 4 procedure follows the common experimental procedure described above (p. 20).

Reinforcement Schedules. In Experiment 4, VR 4 + VT 12-s delivered 4 points per reinforcement, and DRL 5s delivered 2 points per reinforcement. It was intended that VR 4+ VT 12-s would deliver a higher point density than DRL 5-s.

Experiment 4 results

Verbal Discrimination

All Experiment 4 participants verbally discriminated between hues in the hue perception test. In questionnaire Part 1, all participants verbally discriminated between reinforcement schedules by correctly matching the hue name with relative points density and relative sorting rate.

BL Point Densities

Mean BL point densities are shown under the heading “BL point density” in Table 6. The VR 4 + VT 12-s total point densities were all more than double those of DRL 5-s.

Response Rates

Mean BL sorting rates for Experiment 4 are shown in Table 6 under the heading “BL rate”. As anticipated, mean BL sorting rates are consistently higher under VR 4 + VT 12-s than under DRL 5-s. BL rates under VR 4 + VT 12-s varied from 26.9 responses/min (Dux) down to 26.1 responses/min (Dik). Mean BL rates under DRL 5-s varied less among participants, from 11.1 responses/min (Del) down to 9.6 responses/min (Dik).

Table 6

Experiment 4 Mean Values across Sessions

Participant			Schedules[2]	BL point density[3]	BL rate[4]	Disrupted rate[4]	Relative rate (%)[5]	TPP (%)[6]
Name[1]	M/F	Age						
Dag	F	23	VR 4+VT 12-s	44.3	26.7	18.4	68.9	76.9
			DRL 5-s	20.9	10.9	10.5	95.7	82.8
Del	M	23	VR 4+VT 12-s	45.2	26.4	21.0	79.6	61.8
			DRL 5-s	18.0	11.1	10.4	93.3	72.0
Dik	M	23	VR 4+VT 12-s	45.2	26.1	20.6	78.9	67.5
			DRL 5-s	18.4	9.6	9.1	94.7	73.9
Dux	M	22	VR 4+VT 12-s	44.3	26.0	23.2	90.0	79.6
			DRL 5-s	18.0	10.4	10.3	99.0	84.4

[1] These are not the participants' real names.

[2] VR 4 + VT 12-s delivered four points per reinforcement, while DRL 5-s delivered two points per reinforcement

[3] BL point density is measured in points per minute

[4] Rate is measured in responses per minute

[5] Relative rate represents Disrupted Rate as a percentage of BL rate

[6] TPP represents the percentage of intervals that the CDS numbers were equal during which the "T" key was pressed

Disrupted sorting rates. Mean disrupted sorting rates are shown in Table 6 under the heading "Disrupted rate". The VR 4 + VT 12-s mean disrupted rates are higher than DRL 5-s disrupted rates for each participant. We also see that all disrupted rates are lower than BL rates, showing that the disrupter functioned as designed. However for Dux under DRL 5-s this decrease was minimal.

Relative rates. Mean relative rates are also shown in Table 6 under the heading "Relative rate". These relative rates are consistently lower under VR 4 + VT 12-s than under DRL 5-s.

TPP Manipulation Check

Mean TPP values are shown in Table 6 under the heading "TPP". The mean TPP values under VR 4 + VT 12-s range from 79.6% (Dux) down to 61.8% (Del), and .under DRL 5-s range from 84.4% (Dux) down to 72.0% (Del). Also the mean TPP value under VR 4 + VT 12-s was lower than that under DRL 5-s for each participant.

Relative Rate as a Function of Reinforcement Schedule

Relative rates across sessions under DRL 5s and VR 4 + VT 12-s reinforcement schedules are shown in Figure 4. Relative rates were calculated relative to session BL mean rates. For all participants we see that the DRL 5s relative rates are greater than that of VR 4 + VT 12-s, although for Dux this is not the case in Session 1.

Experiment 4 Discussion

In Experiment 4 the conditions necessary for testing the BMM have been met: (a) higher reinforcer density under VR 4 + VT 12-s than under DRL 5-s, and (b) the disrupter lowered response rates. In addition other design conditions were met:

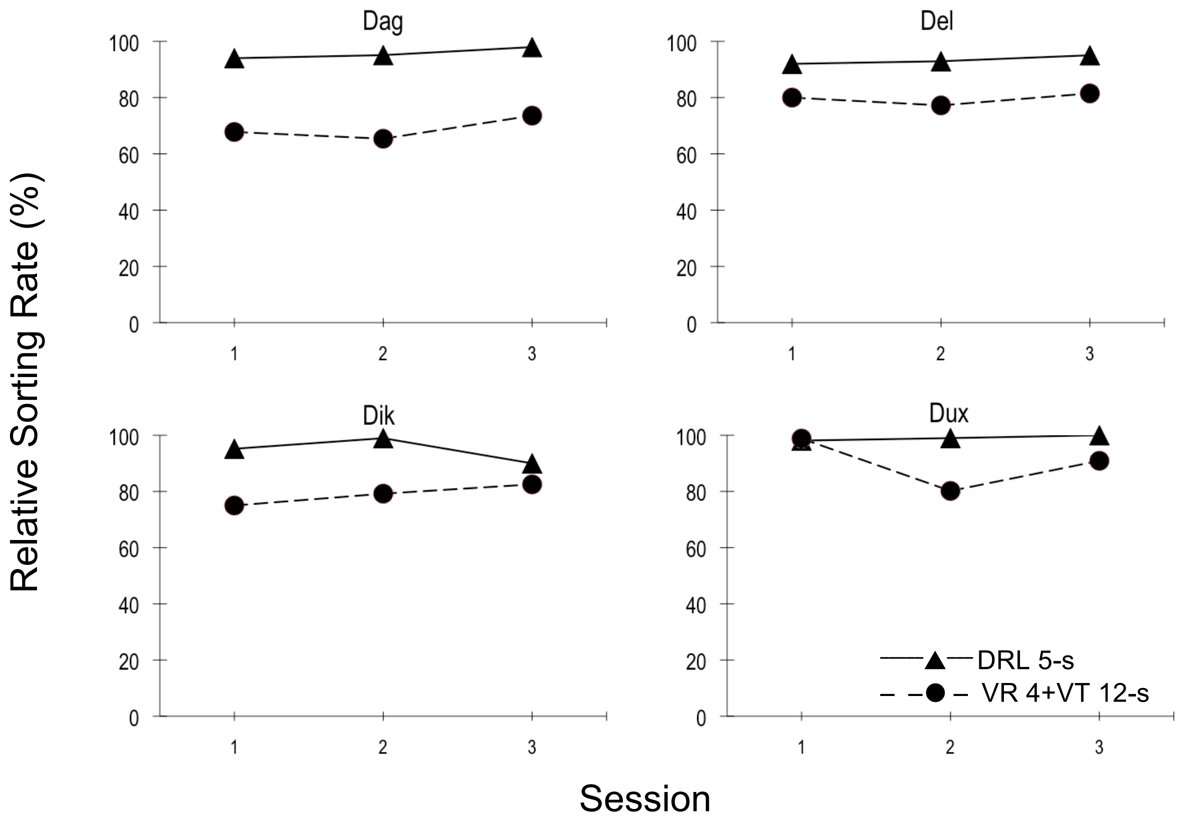

Figure 4. Experiment 4 relative sorting rates under DRL 5-s and VR 4 + VT 12-s.

(a) CDT compliance, (b) verbal discrimination between reinforcement schedules, and (c) greater response rates under VR 4 + VT 12-s than under DRL 5-s.

In Experiment 4 the BMM prediction is that sorting resistance to change under VR 4 + VT 12-s should be greater than under DRL 5-s because VR 4 + VT 12-s had the greater point density. Thus the BMM predicts relative rates under VR 4 + VT 12-s should be higher than those under DRL 5-s. However, in Experiment 4, relative response rates under DRL 5-s were higher than those under VR 4 + VT 12-s, contradicting the BMM hypotheses.

General Discussion

The current study's four experiments were designed to investigate the validity the BMM hypotheses. If the BMM prediction holds, then relative response rate resistance to change consistently should be higher under the reinforcement schedule providing the greater point density.

The present experiments were a systematic replication of Mace et al. (1990)'s research. Like in Mace et al., the principal behaviour was a categorical sort, the disrupter was external, and the experiments tested the effects of response-dependent reinforcement alone (Experiments 1 and 2) and of a combination of response-dependent and response-independent reinforcement (Experiments 3 and 4). Unlike Mace et al., DRL and VR schedules were used (rather than VI). Also differing point densities were established by varying the number of points delivered per reinforcement. In addition explicit computer-administered instructions and feedback were used, and participant verbal behaviors were sampled.

In all four experiments, experimental conditions prerequisite to testing the BMM were met: (a) the disrupter caused response rate reduction, and (b) the point densities differed between schedules. In addition, overall sorting rates under DRL 5-s were lower than under VR 4. Also participants verbally distinguished between schedules based on S^D and point density.

My current research addressed two criticisms: (a) that of Galbicka and Kessel (2000), that BMM research has relied too much on VI schedules; and (b) that of Harper and McClean, (1992) and McClean and Blampied (1995), that BMM research has almost exclusively used internal rather than external disrupters.

Resistance to Change

In Experiments 1 and 3, resistance to change in relative response rate was greater under the greater reinforcer density schedule (DRL 5-s and DRL 5-s + VT 6-s respectively). However in Experiments 2 and 4, resistance to change was greater under the lesser reinforcer density schedule (DRL 5-s in both experiments). Thus it seems that Experiment 1 and 3 data support the BMM, while Experiment 2 and 4 data contradict the BMM.

However in all cases it was under a DRL based schedule (with slower response rates) rather than under VR (with higher response rates) that resistance to disruption was greater. Overall my data did not support the BMM because resistance to disruption did not consistently match point density.

Under the current experimental conditions, it appears that behavioral momentum (resistance to disruption) was influenced by some factor or factors other than reinforcer density. Nevin et al. (2001) and Lattal et al. (1998) compared resistance to disruption under interval versus ratios schedules, with reinforcer densities were equated. They found that responding under interval schedules was more resistant to change than responding under ratio schedules, and argued that factors other than reinforcer density also influence resistance to disruption. Although my experiments used DRL and VR schedules with differing point densities, nonetheless those authors' opinions about what factors might influence resistance seem relevant.

DRL, VR, and VI Schedules

The BMM does not specify the nature of reinforcement schedules as a factor affecting resistance to change. VI schedules have some properties different than those of DRL or VR schedules. One property is that VI response rates are high (but not as high as VR rates) and stable. Another property is that VI reinforcer density does not decrease appreciably with response rate decrease, while VR reinforcer density decreases as a linear function of response rate decrease. This later property seems pertinent to BMM research, with its emphasis on relative reinforcer densities. The relation between response rate and reinforcer density for DRL, VR, and VI reinforcement schedules is discussed in Appendix B. Some research evidence (including that of my current study) indicates that the nature of schedules used does affect resistance to change.

Response Rate versus Schedule Effect

Because response rates under DRL 5-s were lower than those under VR 4, and resistance to disruption under DRL 5-s was greater than that under VR 4, response rate seems to be a factor negatively related to relative resistance. Nevin et al. (2001)

found that higher response rates (under ratio schedules) were associated with lower resistance to change, and relatively lower response rates (under interval schedules) were associated with greater resistance to change. In other studies, Lattal (1989) and Nevin (1974) established slow response rates using tandem DRL schedules. They found that slower response rates displayed more resistance to change than did higher response rates (under FR in Lattal, and under DRH in Nevin). These results are in line with my data. My use of DRL versus VR reinforcement schedules (but not VI schedules) was a generalization from these experiments as well.

Lattal et al. (1998) did not find consistent differences in response rate between ratio and interval schedules with equated reinforcer densities. They discussed how interval schedules' features compare to those of ratio schedules, and suggested that the differences may combine to produce responding under interval schedules that is less susceptible to disruption. These features are: (a) lower response requirement, (b) lower response rate, (c) reinforcement of longer inter-response intervals, and (d) a lower correlation between response rate and reinforcer density. A general restatement is that responding under interval schedules has lower response cost than under ratio schedules. It is interesting that this comparison of interval schedule features to those of ratio schedules also pertains to DRL schedules relative compared to ratio schedules. And DRL (like VI) schedules also have lower response cost.

In the extended BMM metaphor suggested by Houlihan and Brandon (1996), both reinforcement and response cost are considered to be behavioral forces. Then it would seem that the effect of reinforcement (based on reinforcer density) would be less when opposed by higher response cost. This would explain the Lattal et al.

(1998) and Nevin et al. (2001) findings. It could also in part explain the current findings, since responding under DRL 5-s had lower response cost, while responding under VR 4 had higher response cost.

Alternate DRL Rate Measure

Compliance with the DRL schedule consisted of two parts, a pause of 5s followed by completing a sorting response. With human participants, waiting 5s likely is based on counting out the 5s privately. Counting is a verbal behavior already in the participants' behavioral repertoire, so it could easily be evoked through instruction.

In the simplest case, participants' responses under DRL 5-s could be considered to be a behavioral chain consisting of: (a) pause 5s or more, followed by (b) sort a triangle under a FR 1 reinforcement schedule. Assuming for simplicity that the pause duration is only 5.0s, the response rate calculation used in this study was 1 reinforcement per (5.0s plus the time to complete a sort). However in this simplest case, sorting response rate could instead be based solely on the time taken to sort a triangle, and should not include the pause. This would result in higher re-calculated sorting rates under DRL 5-s as well as higher matching point densities. For example, if each sort under DRL 5s took only 3s (lower than most VR 4 rates), the approximate calculated reinforcement density would increase from one reinforcement per 8s (7.5 reinforcements/min) to a re-calculated value of one reinforcement per 3s (20 reinforcements/min). From this we would see re-calculated point densities proportionally greater under DRL 5-s, and these revised point densities would be much greater than those under VR 4 in Experiments 1 and 3. In Experiments 2 and 4, the degree to which VR 4 point densities were higher would be less. It is possible that, with such recalculated rates, sorting rate disruption under DRL 5-s might also be revised.

However, at least for some participants, the pause and sorting were concurrent to a degree. For example, some participants were observed to immediately drag a triangle to a position where the target was "trapped" in a corner while counting, thus being ready for immediate completion of the sort. Then, for the remainder of the pause they could attend to the CDT, and when the pause ended, would complete the sort. However separate measurements of the actual duration of pauses and sorts were not collected, and thus results based on this alternate interpretation are not available. Likewise re-calculated relative sorting rates that perhaps would result in altered resistance patterns are not available.

Influence of Verbal Behavior

Given that the participants in the current experiments were human, verbal behaviors may have been another particularly important factor influencing resistance to disruption.

Killeen (1994) reminds us that what an experimenter intends as effects of a reinforcement schedule is less important than how an organism actually reacts to the schedule. With human participants, some reactions are verbal behaviors. In the current study verbal behaviors were not the focus of the investigation, other than confirming verbal discrimination between schedules. However questionnaire responses did provide more information about participant behaviors, so it seems worthwhile to investigate them.

The focus of BMM research is how contingencies (response-contingent and response-independent) affect resistance to change. However behavioral psychologists, including B. F. Skinner, have shown that direct contingency-based influences are not sufficient to explain human behavior (Hayes & Blackledge, 2001).

Rules

The ability to formulate and use rules to control behavior is a human attribute. Rules specify context, behavior, and consequences. An example rule for responding under DRL 5-s is "When the triangles' hue is lime, if I wait 5s before sorting another triangle, I will receive points, but if I don't wait long enough, I will miss points."

Hayes, Strosahl, and Wilson (1999, p 27) summarize the benefits of rules: "Rule-governed behavior allows human beings to respond in very precise and effective ways where contingency-based learning can be ineffective or even lethal, such as when the consequences of behavior are subtle, small, temporally remote, cumulative, or probabilistic." Rules (and instructions) can enhance or impede human sensitivity to contingencies (Madden et al., 1998; Torgrud and Holborn, 1990, Kollins et al. 1997). Thus rules may influence resistance to disruption.

Rules or other verbal stimuli can be used to occasion other rule-governed behavior. For example, in the description of the DRL 5-s rule described above, counting behavior is implicitly required, and counting is itself a verbal behavior.

Participant Rules

If a participant in the current study were to generate a rule that matched the BMM prediction, it could be of the form "In order to obtain the maximum number of points, maintain response rate more under conditions where points are delivered at a higher rate." Under VI schedules, adherence to this rule would only minimally affect earned point density because, under VI schedules, reinforcer density is minimally affected by a change in response rate.

In the present study, participants were trained using computer delivered written instructions and prompts, including descriptions of the basic DRL 5-s and VR 4 contingencies. In addition, point totals were constantly displayed and inter-element messages drew attention to both the S^D hue and the number of points earned in the previous element. These factors affect participants through verbal stimuli and may have helped participants to verbally discriminate between conditions and to formulate rules or strategies.

If the various participant-generated questionnaire responses were amalgamated into one composite rule, that rule would emphasize attending more to sorting than CDS (and CDT) under VR 4, while attending relatively less to sorting and more to CDS (and CDT) under DRL 5-s. Such a rule implicitly acknowledges that, when sorting under DRL 5s, less attention is required to maintain sorting rate, so more attention is available for CDS and earning CDT contingent points. Participant-generated responses to questionnaire parts 2 and 3 are summarized in Appendix E.

This participant-generated rule would seem to exploit DRL 5-s and VR 4 properties more effectively than could a BMM rule based solely on point densities. This participant-generated rule also is consistent with the reliably higher TPP values under DRL than under VR. Note that these TPP data, as well as some participant generated verbal responses, imply that participants were actually exerting more effort on sorting (and less on CDS and CDT) under VR 4 than under DRL 5-s, independent of which reinforcement schedule provided the greater point density.

Now that we have "heard" from the participants, it seems worthwhile to look again at different behavioral factors, and how they might relate to resistance to behavioral change.

Disrupter Effectiveness

The disrupter's purpose was to reduce sorting rates, and it did so by means of a CDS along with a CDT. Thus there was competition for resources between the two concurrent tasks: sorting and the CDT. The TPP values consistently decreasing from CDS1 to CDS2 illustrates this competition, with apparently less attention on the CDS and CDT likely accounting for this TPP decrease (see Appendix C).

For some participants in each of the 4 experiments, response rate did not decrease from CDS1 to CDS2 (mostly under DRL 5-s related schedules, see Appendix C)). This unanticipated lack of incremental disruption at CDS2 was likely due, at least in part, to the balance of resources shifting even more towards sorting from the concurrent disrupter. This effect was one of the reasons for averaging sorting rates across trials in each session.

It seems that disrupted sorting rate data might have been more consistent if disruption effects (decrease in relative response rate) were larger, as they were in Mace et al. (1990). The disruption effect might be increased by (a) reducing the mean interval before CDS numbers could become equal, (b) increasing the frequency of

CDS numbers changing, and (c) increasing the number of points delivered per "T" press as well as making delivery of these CDT-contingent points more discriminable.

Topics for Future Research

My present research went beyond the boundaries of typical BMM research by using DRL and VR schedules, with their differing response rates and response requirements. The BMM did not accurately predict response rate resistance to change in the current research, and this raises the question of what other factors influenced resistance. For example, to what extent are differences in absolute response rates related to resistance to change?

VR versus VI. It would be interesting to extend the current procedures to compare relative response rates under VR and VI reinforcement schedules. Then differences between absolute response rates would be less than those under VR and DRL. Like in Lattal et al. (1998) and Nevin et al. (2001), VR and VI reinforcer densities could be yoked, testing their finding that responding under VR shows less resistance than under VI. Perhaps as well reinforcer densities could be altered to find a point of equivalence where schedule differences balanced reinforcer density differences.

Ratio schedule versus ratio schedule. Because relative response rates under ratio schedules seem more susceptible to disruption than under DRL or VI schedules, the comparison of resistance to change in responding under different types of ratio schedules (e.g., VR, FR, PR) could shed light on the influence of both schedule and response rate factors.

Differing moderate rate schedules. In addition, resistance to change between schedules with moderate but differing response rates could be compared, using differential reinforcement of moderate response rate (DRM) reinforcement schedules. The use of a simpler behavior than sorting (e.g., simple key pressing or a key press sequence, with higher possible response rates) might make such comparisons easier. With humans, differing DRM response rates could be established through the use of instruction, prompts, and reinforcement.

What all these suggested lines of research have in common is that they would explore reinforcement schedule and absolute response rate effects. Thus they could further illuminate my conclusions as well as of those of Lattal et al. (1998) and of Nevin et al. (2001), all of which concluded that the BMM does not take into consideration all important variables relevant to resistance to behavioral change.

References

Cohen, S.L. (1996). Behavioral momentum of typing behavior in college students. Journal of Behavior Analysis and Therapy, 1, 36-51.

Cohen, S.L. (1998). Behavioral momentum: The effects of the temporal separation of rates of reinforcement. Journal of the Experimental Analysis of Behavior, 69, 29-47.

Cohen, S.L., Riley, D.S., & Weigle, P.A. (1993). Tests of behavior momentum in simple and multiple schedules with rats and pigeons. Journal of the Experimental Analysis of Behavior, 60, 255-291.

Galbicka, G., & Kessel, R. (2000). Experimenter momentum and the effect of laws. Behavioral and Brain Sciences 23, 97-98, (Commentary on Nevin & Grace, 2000).

Harper, D.N., & McClean, A.P. (1992). Resistance to change and the law of effect. Journal of the Experimental Analysis of Behavior, 57, 317-337.

Hayes, S.C., & Blackledge, J.T. (2001). Language and cognition: Constructing an alternative approach within the behavioral tradition, in *Relational Frame Theory: A Post-Skinnerian Account of Human Language and Cognition*, S.C. Hayes, D. Barnes-Holmes, and B. Roche, eds., pp. 3-20. NY; Kluwer Academic / Plenum Publishers.

Hayes, S.C., Strosahl, K.D., & Wilson, K.G. (1999). Acceptance and Commitment Therapy: An Experiential Approach to Behavior Change. NY; The Guilford Press.

Houlihan, D., & Brandon, P.K. (1996). Compliant in a moment: A commentary on

Nevin. Journal of Applied Behavior Analysis, 29, 549-555.

Killeen, P.R. (1994). Mathematical principles of reinforcement. Behavioral and Brain Sciences 17, 105-135.

Killeen, P.R., & Hall, S.S. (2001). The principal components of response strength. Journal of the Experimental Analysis of Behavior, 75 (2), 111-134.

Kollins, S.H., Newland, C., & Critchfield, T.S. (1997). Human sensitivity to reinforcement in operant choice: How much do consequences matter? Psychonomic Bulletin and Review, 4 (2), 208-220.

Lattal, K.A. (1989). Contingencies on response rate and resistance to change. Learning and Motivation, 20, 191-203.

Lattal, K.A. (2001). The human side of animal behavior. The Behavior Analyst, 24, 147-161.

Lattal, K.A. & Abreu-Rodregues, J. (1997). Response-independent events in the behavioral stream. Journal of the Experimental Analysis of Behavior, 68 , 375-398.

Lattal, K.A. & Perone, M. (1998a). The experimental analysis of human behavior. In Lattal, K.A. & Perone, M. (Eds.). *Handbook of research methods in human operant behavior* (pp. 3-14). NY: Plenum.

Lattal, K.A. & Perone, M. (Eds.). (1998b). *Handbook of research methods in human operant behavior*. NY: Plenum.

Lattal, K.A., Reilly, M.P., & Kohn, J.P. (1998). Response persistence under ratio and interval reinforcement schedules. Journal of the Experimental Analysis of Behavior, 70, 165-183.

Mace, F.C., Lalli, J.S., Shea, M.C., Lalli, E.P., West, B.J., Roberts, M., Nevin, J. A. (1990). The momentum of Human Behavior in a natural setting. Journal of the Experimental Analysis of Behavior, 54, 163-172.

Madden, G.J., Chase, P.N., & Joyce, J.H. (1998). Making sense of sensitivity in the human operant literature. The Behavior Analyst, 21, 1-12.

Marr, M.J. (1992). Behavior dynamics: one perspective. Journal of the Experimental Analysis of Behavior, 57, 249-266.

Mauro, B.C., & F.C. Mace. (1996). Differences in the effect of Pavlovian contingencies upon behavioral momentum using auditory versus visual stimuli. Journal of the Experimental analysis of Behavior, 65, 389-399.

McLean, A.P., & Blampied, N.M. (1995). Resistance to reinforcement change in multiple and concurrent schedules assessed in transition and at steady state. Journal of the Experimental Analysis of Behavior, 63, 1-17.

Nevin, J.A. (1974). Response strength in multiple schedules. Animal Learning and Behavior, 12, 363-370. Journal of the Experimental Analysis of Behavior, 21, 389-408.

Nevin, J.A. (1984). Pavlovian determiners of behavioral momentum. Animal Learning and Behavior, 12, 363-370.

Nevin, J.A. (1988). Behavioral momentum and the partial reinforcement effect. Psychological Bulletin, 103, (1), 44-56.

Nevin, J.A. (1992). Behavioral contrast and behavioral momentum. Journal of Experimental Psychology, 18 (2), 126-133.

Nevin, J.A., Grace, R.C., Holland, S., and McClean, A.P. (2001). Variable-ratio versus variable-interval schedules, response rate, resistance to change, and preference. Journal of the Experimental Analysis of Behavior, 76, 43-74.

Nevin, J.A., Mandell, C., & Atak, J.R. (1983). The analysis of behavioral momentum. Journal of the Experimental Analysis of Behavior, 39, 49-59.

Nevin, J.A., Smith, L.H., and Roberts, J. (1987). Does contingent reinforcement strengthen operant behavior? Journal of the Experimental Analysis of Behavior, 48, 17-33.

Nevin, J. A., Tota, M.E., Torquato, R.D., and Shull, R.L. (1990). Alternative reinforcement increases resistance to change: Pavlovian or operant contingencies? Journal of the Experimental Analysis of Behavior, 53, 350-379.

Newton, I. (1687/1952). Mathematical Principles of Natural Philosophy. (A. Motte, Trans.) University of Chicago. (Original work published 1687).

Pilgrim, C. (1998). In Lattal, K.A. & Perone, M. (Eds.). (1998). *Handbook of research methods in human operant behavior* (pp. 15-44). NY: Plenum.

Plaud, J.J., Gaither, G.A., & Lawrence, J.B. (1997). Operant schedule transformations and human behavioral momentum. Journal of Behavior Therapy and Experimental Psychiatry, 28 (3), 169-179.

Sidman, M. (1960). The Tactics of Scientific Research: Evaluating Experimental Data in Psychology. Boston: Authors Cooperative, Inc.

Skinner, B.F. (1938) The Behavior of Organisms: An Experimental Analysis New York: Appleton-Century-Crofts

Slivinski, J.G. (2001). *A test of the behavioral momentum model with human participants.* Unpublished master's thesis, University of Manitoba, Winnipeg, Canada.

Torgrud, L.J. & Holborn, S.W. (1990). The effects of verbal performance descriptions on non-verbal operant responding. Journal of the Experimental Analysis of Behavior, 54, 273-291.

Appendix A

Fundamental Behavioral Principles

Behavioral psychologists focus on interactions between behaviors and environmental stimuli. Behavior alters the organism's relation to the environment, by increasing the probability of reinforcing stimuli or by decreasing the probability of aversive stimuli. When an antecedent stimulus is highly correlated with such behavior and its consequences, an organism emits the behavior mainly or exclusively in the presence of that stimulus, and not in its absence. This controlling stimulus is called a discriminative stimulus (S^D). Such a behavior under the control of an S^D is called a discriminated operant.

During learning, behavioral change occurs along a probability gradient so that the probability of relevant contingencies changes to the advantage of the organism. For example, while exploring an operant chamber, a hungry, naïve rat encounters a lever and depresses it, causing a food pellet (reinforcer) to be delivered. Due to this relation between food delivery and lever pressing, the rat increases its lever pressing frequency, thus increasing food access. In balance, some learned behaviors are not to the advantage of the organism (e.g., gambling addictions, eating disorders.

Generally learning (adapting to environmental changes) is adaptive for an organism. However there also can be value in resistance to change. An organism benefits from behavioral stability by being able to exploit environmental regularities, while ignoring random local variations. On the other hand, the organism also benefits from a degree of variability in emitted behaviors. This variability allows adaptation when more global environmental changes occur. So both the perseverance of a behavioral pattern (resistance to change) across random fluctuations and learning across systematic environmental changes can be adaptive.

Reinforcement Schedules

In behavioral research, consequences (reinforcers) often influence behavior. A reinforcement schedule clearly defines the conditions (how, when, what) under which reinforcement is delivered. These conditions are typically based on time intervals, response counts, response rates, or some combination thereof. Reinforcement can be delivered dependent solely on the presence of the S^D, that is, without any response requirement (stimulus-dependent and response-independent). Reinforcement also can be delivered contingent on responding (response-dependent). With discriminated operants, response-dependent reinforcement is, by definition, also stimulus-dependent because it occurs in the presence of the S^D. However stimulus-dependent reinforcement need not be response-dependent.

Even in experiments with largely response-independent reinforcement, some response-dependent reinforcement seems necessary to establish and maintain steady state responding (Killeen, 1994). Table A gives examples of reinforcement schedules used in the current study. Appendix B discusses the relation between response rate and reinforcer density for VI, VR, and DRL schedules.

Response Measures

When analyzing behavior, a large number of instances of a behavior are typically observed. Average values of the most pertinent measures are used (e.g., response rate, intensity, response probability, response latency).

Table A

Example Reinforcement Schedules

Schedule	Name	Condition for reinforcement
VR 4	Variable Ratio	Response-dependent: reinforcement is delivered after completion of a variable number or responses (M = 4).
DRL 5-s	Differential Reinforcement of Low response rate	Response-dependent: reinforcement is delivered after a response only if the duration since the previous DRL 5-s delivered response is at least 5s.
VT 6-s	Variable Time	Stimulus-dependent and response-independent: reinforcement is delivered after a variable interval (M = 6 s) with no response necessary.
VI 12-s	Variable Interval	Stimulus-dependent and response-independent: reinforcement is delivered after a variable interval (M = 12 s) with no response necessary.
VR 4 + VT 12-s	Variable Ratio concurrent with Variable Time	This compound schedule is partly response-dependant and partly response-independent, with the two reinforcement criteria operating concurrently and independently, that is, reinforcers are delivered when either criterion is met.

Skinner (1938) stated that response rate is the most convenient measure of strength of responding. Killeen and Hall (2001) state that response rate, response latency, resistance to change (behavioral momentum), and response probability are all positively correlated behavioral measures. Killen and Hall relate these measures to a more general "response strength" construct, with response rate as the best predictor of response strength and response probability the next best. In the current study response rate and resistance to change were negatively related.

Experimental Designs

In operant behavioral research, for each experimental participant comparisons are made within that participant's data in order to determine experimental effects. Comparisons typically are not made to other participants' data. Such experiments are said to be of single organism design.

In a typical single organism experiment, different experimental manipulations are associated with different S^D's. Ideally the differential experimental effects occur in the presence of the corresponding S^D's, and the relation between manipulation and effect is clear. For example, in an alternating condition experiment, the ideal would be that the experimental effects clearly change as experimental conditions alternate from one state to another. Single organism experimental designs and research considerations are discussed thoroughly in Sidman (1960), including multi-element designs as used in the present research.

Operant behavioral research using human participants presents some unique challenges, limitations, and benefits. Lattal and Perone (1998b) present authored chapters on various considerations and methods used in human operant research.

Appendix B

Nature of Reinforcement Schedules

Typically DRL schedules result in a low response rate, VR schedules result in high near maximum response rates, and VI schedules result in stable intermediate response rates (Sidman, 1960, p 133). Response rate affects reinforcer density under these reinforcement schedules to varying degrees.

Because reinforcer density is the main resistance-determining factor in the BMM, it seems worthwhile to investigate how disrupting response rate under these schedules affects reinforcer density. Nevin et al. (2001) stated that, when compared to interval schedules, one factor in why ratio schedules display relatively lower resistance to change might be the ease with that reinforcer density diminishes with response rate.

DRL and VR response-dependent reinforcement contingencies were used in the current study, while VI is the most common used type of schedule used in BMM research. Hence these three types of response-dependent reinforcement schedules will be discussed.

Variable Ratio Schedules

Under VR schedules, delivery of reinforcement is largely independent of time. With ratio schedules such as VR P, a reinforcer is delivered on average every P responses, so on average

$$R = \frac{r}{P}$$

where R is reinforcer density (reinforcement rate) and r is response rate. So with ratio schedules, change in rate would produce a proportional change in reinforcer density. For example, if r decreases by 20% then R would also decrease by 20%.

Limits to VR response rate. Response rate under variable ratio schedules is limited by resources committed to the task. Extra effort results in faster response rates, and that in turn produces a greater reinforcer density. Various factors (e.g., attention, fatigue, reaction time, skill) can limit response rate. In addition, some resources may be shared with concurrent tasks. If extra resources are sparse, demands of concurrent tasks (e.g., the CDS and CDT used in the current study) would reduce resource commitment to responding and thus reduce response rate.

Variable Interval Schedules

For a VI P-s schedule, the soonest that reinforcement could occur is, on average, after P seconds elapse. This would provide a maximum reinforcer density of 1/P reinforcers per second. Assuming that mean delay after the VI duration of P-s has elapsed is 1/2r, reinforcer density R is approximated by the equation

$$R = \frac{1}{P + \frac{1}{2r}}$$

This is a hyperbolic function of r, with asymptote R= 1/P. Thus, assuming that response rates are great enough that 1/2r is small compared to Ps, reinforcer density is relatively insensitive to changes in rate. In BMM research using VI schedules, response rates are large enough to ensure that reinforcer density is essentially stable.

Limits to VI response rates. VI typically results in fast, steady responding. However increase in response rate results in little increase in reinforcer density. Hence one expects rates under VI schedules to be typically fast but not as fast as under VR schedules, because there is no significant “pay-off” for faster responding.

Hence response cost would be less salient than under VI schedules than under VR schedules.

DRL Schedules

Under a DRL P-s contingency (e.g., DRL 5-s), in order to earn a reinforcer, the participant must wait at least P seconds between completed responses. So maximum reinforcer density under a DRL P-s schedule would be 1 reinforcer every P seconds (i.e., 1/P reinforcers per second). If a response were to occur before P seconds elapse, no reinforcer would delivered. More completely, maximum DRL P-s reinforcer rate would, assuming a steady rate, be:

$$R = r \quad if \quad r \leq 1/p \, , \quad R = 0 \;\; otherwise$$

If the rate were not steady, actual reinforcer rate would depend on the proportion of responses for which the actual time elapsed since last DRL delivered reinforcer or last response was greater than P s.

Reinforcer Density Resistance to Change

Thus it seems that, in ratio, interval, and DRL schedules, a decrease in response rate leads to a decrease in reinforcer density. Although reinforcer density is directly proportional to response rate for both VR and DRL schedules, one would expect that response rate would be less affected by disruption under DRL schedules because response rate and response cost are lower. For interval schedules, where response rate is high enough that reinforcer rate is near maximum, decrease in response rate produces a much smaller decrease in reinforcer density.

So reinforcer density change does not decrease significantly under either interval or DRL schedules, whereas it does for ratio schedules. Experiments with pigeons have shown that responding shows more resistance to change under interval schedules than under ratio schedules with the same reinforcer density (Nevin et al, 2001). Nevin et al. also found that higher response rates under VR schedules are correlated with lower VR resistance to change. Higher response rate is associated with higher response cost and lowered preference for that schedule.

Appendix C

Effects of CDS Levels

Both sorting rate and TPP were reduced with introduction of disruption. When disruption (CDS) was present, the CDT (“T” pressing) and triangle sorting were concurrent tasks. In fact, the competition between sorting and CDT for attention and time helps explain why the two tasks disrupted each other.

An analysis of response rates and TPP values across CDS levels might give information on the relative effectiveness of the two CDS levels and shed some light on how these two tasks competed for resources. It was anticipated that CDS2 would cause more sorting rate disruption than would CDS1. However, this was not always the case.

Sorting Rates across CDS Levels

Table C1 shows relative rates at CDS1 and at CDS2 under the heading “CDS1 relative rate (%)” and “CDS2 relative rate (%)”for each of the 4 experiments. CDS1 relative rate values less than 100% indicate that mean CDS1 sorting rate was less than mean BL sorting rate, that is, sorting rate decreased.

Looking at CDS1 relative rates for all participants in all 4 experiments, we see that all CDS1 rates are less than BL rates (i.e., less than 100%), although for some Experiment 4 participants, the values are above 96% (under DRL 5-s). This shows that the disrupter was effective at CDS level 1. Similarly CDS2 relative rates are less than 100% (except for Dux under DRL 5-s in Experiment 4), showing that a disruption effect is evident under CDS level 2 as well. Generally this shows that that the disrupter was effective to some extent in all experiments at both levels.

Next comparing relative rates at CDS2 to that at CDS1, we see that most CDS2 relative rates are less than those at CDS1. However some CDS2 relative rates are equal or even greater than CDS1 rates: (Experiment 1) Ada under DRL 5-s, (Experiment 2) Bas and Bon under DRL 5-s , (Experiment 3) all four participants under DRL 5-s + VT 6-s, and Cob also under VR 4, and (Experiment 4) Dag, Del, and Dux under DRL5s, and Del also under VR 4 + VT 12-s. This indicates that the intended incremental disruption at CDS2 over CDS1 did not occur for some participants.

CDS2 utility

The CDS2 disrupting effect was less consistent than anticipated, and this obscures data patterns to some extent. Two ways to reducing this confusion are:

(1) Consider only CDS1 effects. This has the advantage of ignoring the CDS2 versus CDS1 variability. Table B1 gives an overall picture of the resistance pattern based only on CDS1 under the heading "CDS1 relative rate (%)". Based on CDS1 rate data alone, we would conclude that sorting rate had more resistance to change under DRL 5-s based schedules in all experiments.

(2) Another solution would be to average (mean) the CDS1 and CDS2 rates. This would moderate CDS2 rate variability while still using all data, and this is the method used in the body of the current study.

Nonetheless the conclusions based on both solutions were the same, that is, that resistance to change was greater under DRL 5-s based schedules than under VR 4 based schedules. .

Table C1
Mean Sorting Rates across CDS Levels

PART A				PART B			
Subject	Schedule	CDS1 relative rate (%)	CDS2 relative rate (%)	Subject	Schedule	CDS1 relative rate (%)	CDS2 relative rate (%)
Experiment 1				Experiment 3			
Aby	VR 4	75.7	66.2	Cat	VR 4	83.2	71.0
	DRL 5-s	89.0	79.0		DRL 5-s+VT 6-s	82.8	91.5
Ace	VR 4	82.2	68.5	Cec	VR 4	77.0	73.0
	DRL 5-s	90.9	83.3		DRL 5-s+VT 6-s	80.2	80.0
Ada	VR 4	74.4	56.5	Civ	VR 4	84.8	79.2
	DRL 5-s	68.4	75.5		DRL 5-s+VT 6-s	84.5	84.5
Arn	VR 4	80.5	65.4	Cob	VR 4	87.8	89.7
	DRL 5-s	86.8	68.4		DRL 5-s+VT 6-s	89.7	90.2
Experiment 2				Experiment 4			
Bas	VR 4	62.3	58.4	Dag	VR 4+VT 12-s	73.5	64.5
	DRL 5-s	90.8	89.5		DRL 5-s	96.3	94.5
Bet	VR 4	70.0	59.3	Del	VR 4+VT 12-s	79.8	78.3
	DRL 5-s	84.0	80.8		DRL 5-s	91.5	98.0
Bix	VR 4	66.8	48.4	Dik	VR 4+VT 12-s	82.5	76.2
	DRL 5-s	75.2	59.0		DRL 5-s	96.8	92.0
Bon	VR 4	84.3	81.2	Dux	VR 4+VT 12-s	89.3	83.3
	DRL 5-s	91.0	89.4		DRL 5-s	97.2	101.5

TPP Variation across CDS Levels

The TPP measure estimates CDT ("T" pressing) response probability. CDS with concurrent sorting disrupts CDT just as the CDS along with CDT disrupts sorting rates. This reciprocal disruption is analogous to Newton's third law of motion, often stated as "for every action there is an equal and opposite reaction".

TPP values at CDS1 are shown in Table C2 under the header "CDS1 TPP (%)". The ratios of TPP at CDS2 to that at CDS1 are shown under the header "TPA ratio". Showing the relative change from CDS1 TPP to CDS2 TPP allows comparison between schedules, just as relative rates do when investigating relative rate resistance.

Looking at CDS1 TPP for all participants (in all 4 experiments) shows that CDS 1 TPP values are all less than 100%, indicating that some possible "T" presses were missed by all participants. Also we can see that CDS1 TPP values under VR 4 based schedules were less than those under DRL 5-s based schedules for all participants, although this difference was minimal for some participants.

The values under the header "TPP Ratio" shows what percentage the CDS2 TPP values are of the CDS1 TPP values. Thus the TPP ratio values indicate relative change between CDS levels, and can be considered an indicator of CDT resistance to change. Looking at all participants in all 4 experiments, we see that the TPP ratios for most participants were to some extent greater under DRL 5-s based schedule than under VR 4 based schedules. Exceptions were Ace in Experiment 1 and Del in Experiment 4, both of whom had a higher rate (but lower TTP) under the VR 4 based schedule. This shows that CDT generally displayed greater resistance under the

DRL 5-s based schedules than under VR 4 based schedules. Thus the pattern of CDT response probability (i.e., TPP) resistance to change is similar to that of relative sorting rates.

Table C2.

Mean TPP Values across CDS Levels

Part A				Part B			
Subject	Schedule	CDS1 TPP (%)	TPP ratio	Subject	Schedule	CDS1 TPP (%)	TPP ratio
Experiment 1				Experiment 3			
Aby	VR 4	54.8	0.500	Cat	VR 4	91.8	63.5
	DRL 5-s	63.7	0.597		DRL 5-s+VT 6-s	96.7	66.8
Ace	VR 4	71.4	0.581	Cec	VR 4	77.8	50.5
	DRL 5-s	84.8	0.454		DRL 5-s+VT 6-s	94.0	67.8
Ada	VR 4	96.2	0.569	Civ	VR 4	91.2	43.8
	DRL 5-s	96.8	0.663		DRL 5-s+VT 6-s	98.2	67.8
Arn	VR 4	94.3	0.413	Cob	VR 4	52.7	20.5
	DRL 5-s	97.3	0.522		DRL 5-s+VT 6-s	66.0	29.8
Experiment 2				Experiment 4			
Bas	VR 4	92.0	0.363	Dag	VR 4+VT 12-s	95.7	60.8
	DRL 5-s	95.7	0.366		DRL 5-s	93.7	76.6
Bet	VR 4	82.0	0.668	Del	VR 4+VT 12-s	78.8	59.4
	DRL 5-s	88.5	0.785		DRL 5-s	96.0	50.0
Bix	VR 4	36.2	0.260	Dik	VR 4+VT 12-s	91.2	48.0
	DRL 5-s	63.2	0.293		DRL 5-s	96.0	54.0
Bon	VR 4	76.0	0.129	Dux	VR 4+VT 12-s	96.5	65.0
	DRL 5-s	68.3	0.340		DRL 5-s	99.5	69.5

Appendix D

Questionnaire

Questionnaire Part 1 is shown in Figures D1, while Parts 2 and 3 are shown in Figure D2. Part 1 was administered after Session 1, while the complete questionnaire was administered after Session 3. Appendix E summarizes participant responses.

Part 1: Please circle the name of the color that best answers each question. If you can't tell, circle the "no difference" answer.

1) With that color did you earn more total points?
   LIME FUCHSIA NO DIFFERENCE
2) That color gave you more points each time you pressed the SPACE bar to accept points?
   LIME FUCHSIA NO DIFFERENCE
3) With that color did you sort triangles faster?
   LIME FUCHSIA NO DIFFERENCE
4) With that color did you use more effort?
   LIME FUCHSIA NO DIFFERENCE
5) With that color did you tried hardest to maintain the sorting rate while having to press the "T" key?
   LIME FUCHSIA NO DIFFERENCE
6) With that color did the 'T' pressing slow down your triangle sorting the most?
   LIME FUCHSIA NO DIFFERENCE
7) With that color was it more difficult to keep sorting at the same rate when you also had to press the "T"? LIME FUCHSIA NO DIFFERENCE
8) With that color did it seem most useful to put in extra effort?
   LIME FUCHSIA NO DIFFERENCE
9) With that color did it seem hardest to keep up the "T" pressing?
   LIME FUCHSIA NO DIFFERENCE

Figure D1. Questionnaire Part 1

Part 2: Please write brief answers in the spaces provided.

When the two numbers blinked faster:

1) how did it affect how you sorted triangles? ______________________________

____

2) how did it affect how hard it was to sort the triangles? ____________________

____

3) how did it affect how hard it was to press the "T" key on time? _______________

____

4) how did it affect how many points you gained? __________________________

____

Part 3: Please write brief answers in the spaces provided.

A) Did you use any rules or strategies to help you gain points while you were sorting triangles? If you did, briefly describe them. ______________________________________

____

B) Did you use any rules or strategies for the "T" key pressing? If you did, briefly describe them. ____

____

C) Did you use any rules or strategies for how to share your effort between the triangle sorting and "T" pressing? If you did, briefly describe them. ______________________________

____

D) Did you notice any other influences on your efficiency, speed, point gain, or fatigue? If so, describe these influences and how they affected you. ______________________________

____

Figure D2. Questionnaire Parts 2 and 3

Appendix E

Participants' Questionnaire Responses

The main purpose of the questionnaire was to ascertain if participants verbally discriminated between schedules' point densities on the basis of the associated S^D hues (Lime and Fuschia). This was shown to be true in participants' responses to Part 1 (multiple-choice).

During training sessions, instructions and feedback presented written descriptions of required tasks and response-dependent contingencies. During each trial, point totals were maintained, and after each element a summary of points from the previous schedule was displayed. It seems likely that participants' behaviors were under the influence of these instructions and information. In addition participants may have been operating under the control of self-generated rules regarding sorting and CDT. Although investigation of participant verbal behavior was not the focus of the current study, nonetheless participant responses provide information about the participants' behaviors from the their own perspectives. This appendix considers participants' questionnaire responses from all four experiments, and discusses both participant remarks (observations) and rules.

The questions in questionnaire Parts 2 and 3 asked for written responses based on participants' observations and strategies. The questions fell into two categories, (a) asking about the effects of the CDS and CDS level, and (b) asking for strategies or rules that the participant used during the experiment.

Summaries of the participants' remarks are listed in Table E, along with the number of participants giving each response. The most frequent remarks (R1 and

Table E

Questionnaire Response Summary

Label*	Response	Number
R1	CDS caused sorting rate decrease, CDS distracted from sorting	17
R2	CDS reduced point density associated with sorting	12
R3	When CDTs were missed a message appeared, briefly slowing down sorting	2
R4	There was a short delay after the CDS pair again became unequal during which a "T" press was still accepted	1
R5	An increase in CDS level slowed down both sorting and "T" press tasks	7
R6	The orientation of triangle sorted did not affect points	3
R7	It was necessary to balance the two tasks to maximize points earned	4
R8	CDT increases total points while sorting under DRL 5-s points, but decreases total points while sorting under VR 4	1
R9	Statement of all sorting and CDT point weights for the participant	1
S1	While under DRL 5-s, first move a triangle near its target, then count 5s while attending to the CDS and CDT	6
S2	Use peripheral vision on triangles and central vision on CDS	5
S3	Place the left thumb at the space bar and left index finger at the "T" key ready to collect points and perform the CDT, while using the right hand to select and move triangles with the mouse	1
S4	Reduce attention to the CDS and CDT under VR 4 to maximize total points from sorting and CDT	4
S5	Increase attention to the CDS under DRL 5-s because less time was needed for sorting, thus maximizing total points	4
S6	Generally attend more to sorting in order to maximize total points	2
S7	After a "T" press and before equal CDS's there is an interval of 3 to 4s during which attention can be profitably focused solely on sorting	2

* Label R indicates a remark or observation, and S indicates a strategy or rule.

R2) described how CDS affected sorting and point acquisition. The most frequent strategies (S1 and S2) gave rules for balancing attention between sorting and "T" pressing.

Participants wrote a variety of responses, some of which draw attention to various situations where they could exploit experimental regularities. One salient example is that the 5s sorting delay under DRL 5-s can be exploited by attending more to the CDT without loss of sorting based points. The other side of the same relation is that, in order to maintain sorting under VR 4 at a high rate, less attention would be paid to the CDS and CDT. Together these uncover a general strategy for optimizing points from sorting. Remarks R7 and R8, as well as strategies S1, S2, S4, S5, and S6, all refer to all or some of this balance. Even strategy S7 points out intervals (after a "T" press) during which attention can be focused entirely on sorting. Individual differences were evident in the number and nature of responses. In addition, the experimenter's impression was that several participants' first language was other than English, suggesting that patterns of language and cultural differences may have affected their verbal behavior. As mentioned earlier, a detailed investigation of verbal factors was not in the scope of the current study.

The various participant strategies could be summarized as follows:

1. Divide attention between sorting and "T" pressing so as to achieve the greatest number of points
    a. Under the VR 4 based schedule, focus more attention and effort on sorting and less on the CDS (and less on the CDT).

   b. Under the DRL 5-s based schedule, focus more attention on the CDS (and CDT) and less on sorting.

2. Exploit hiatuses available due to the nature of the experiment to increase points from the other point source
   a. During the 5 s interval under the DRL 5-s schedule postpone completion of the sort and apply attention to the CDS and CDT to gain more points from the CDT.
   b. During the 3 s interval after two CDS numbers are equal, when they will not yet be again equal, shift the balance of attention to sorting so as to get more points from sorting.
3. Generally focus more attention on sorting because it gives more points than the CDT.

It seems that these summarized strategies exploit the experimental circumstances more effectively than would a strategy simply based on the BMM.

Appendix F

Participant Recruitment

Participants were recruited from introductory psychology courses at the University of Manitoba, and they earned experimental credits towards a course requirement. The total duration of my experiments was equal to the participation duration that provided all experimental credits necessary to completely fulfill this requirement. Note that both forms shown below are displayed at reduced size.

Figure F1 shows the information provided prospective participants during recruitment, while the Experimental Participant Consent Form that participants read and completed in at the first meeting is illustrated in Figure F2. Both figures show the version used for Experiments 1 and 2.

Experiment STEINBACH

Experiment Steinbach needs 10 volunteers. Each volunteer would come 4 days
(two Tuesdays and two Thursdays, from 1:00 to 2:15, starting March 9.)
Each volunteer would earn 8 experimental credits as well as points for small cash prizes.
If you are volunteering for experiment Steinbach:

1) On the participant Civ-up sheet (bubble sheet)
    a) Print your name and telephone and Civ your name
    b) Fill in your student number (print it and fill in the bubbles)
    c) Take the reminder
2) Take a sheet describing Experiment Steinbach

Experimenter's name: Jim Slivinski

Session Times	
Tues. March 9	**Thurs. March 11**
Tues. March 16	**Thurs. March 18**
Attend All 4 sessions	
1:00 PM to 2:15 PM Room P210	

Each session will consist of two 25 minute trials with a 10 minute break between them.

About the experiment:

Experiment STEINBACH is a behavioral experiment. Results from each participant will be looked at individually, not averaged or compared to results of others. There are 4 sessions on Tuesdays and Thursdays (1:00), March 9 through 18.

In the experiment you will move triangles on the computer screen to earn points. These points will earn you tickets for small cash prizes. Each ticket will win you a prize ranging from $0.05 up to $20.00.

First session is Tuesday, March 9 at 1:00 PM in room P210.
Come early if you are not sure where room P210 is.

Figure F1. Recruitment information

Experimental Participant Consent Form

Psychology Experiment **Steinbach** Researcher: Jim Slivinski

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more details, or information not included here, you should feel free to ask. Please take the time to read this carefully, and keep a copy for your records.

The Experiment

You will use the computer mouse to drag triangles from the bottom of the computer screen to matching targets at the top. This will earn you points, and more points will earn you more ticket draws. After the last session you will draw tickets for cash prizes ranging from $0.05 to $20.00. The purpose of the experiment is to gather data on how you sort triangles under different conditions. This data will be automatically recorded.

You are signing up to participate in all 4 sessions.

Session Times - Attend All 4 sessions	
Tues. March 9	Thurs. March 11
Tues. March 16	Thurs. March 18
1:00 PM to 2:15 PM Room P210	

This is a behavioral experiment; your results will be compared only to your own from session to session. Your points and ticket draws are determined only by your own work. Your name or other identifying data will not be used or reported.

After the last experimental session (Thursday, March 18) you will be told generally what the experiment is about. More information about the results will be posted on the door of P204 when the data has all been gathered and analyzed.

Your signature on this form indicates that you have understood to your satisfaction the information about this research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. However if you withdraw, your data will be incomplete, and cannot be used in the study. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

If you are unable to attend a session or have questions, telephone Jim Slivinski (yyy-yyyy), and leave a message. He will call back to arrange a make-up session for you or to answer your questions.

This research has been approved by the Psychology/Sociology Research Ethics Board. If you have any concerns or complaints about this project you may contact the above-named person or the Human Ethics Secretariat at 474-XXXX, or e-mail xxxxxxxx.

A copy of this consent form has been given to you to keep for your records and reference.

_ _

Participant Name (please Print) ____________________________

Participant Signature _______________________ Date: ___________

Researcher Signature ______________________ Date ____________

Figure F2. Informed consent form

Appendix G

Computer Delivered Instructions and Feedback

Screen images are shown which display the experimental screen as well as some computer delivered instructions and feedback.

Basic Screen during an Experimental Trial

Figure G1 shows the screen during a BL 3-minute experimental element (no CDS) at the moment a reinforcer is available, just after a triangle had been dragged to its matching target. Sorting is paused until the space bar is pressed. The triangles and screen border were colored Lime or Fuchsia according to the schedule operating within that element. The point total is at the top left of the screen.

Figure G1. Experiment screen image without CDS.

Between Element Pause Screen

During the pause between 3-minute elements, a message appears on the otherwise blank black screen. It states the number of points earned in the previous element (printed in the S^D hue of that schedule) and also states the name of the color used in the next element (printed in the S^D hue of the next schedule). During training it would also state how sorting points could be gained by describing the upcoming VR 4 or DRL 5-s contingency.

Participant Identification Screen

The participant identification screen is shown in Figure G2. It appears before the instruction screen.

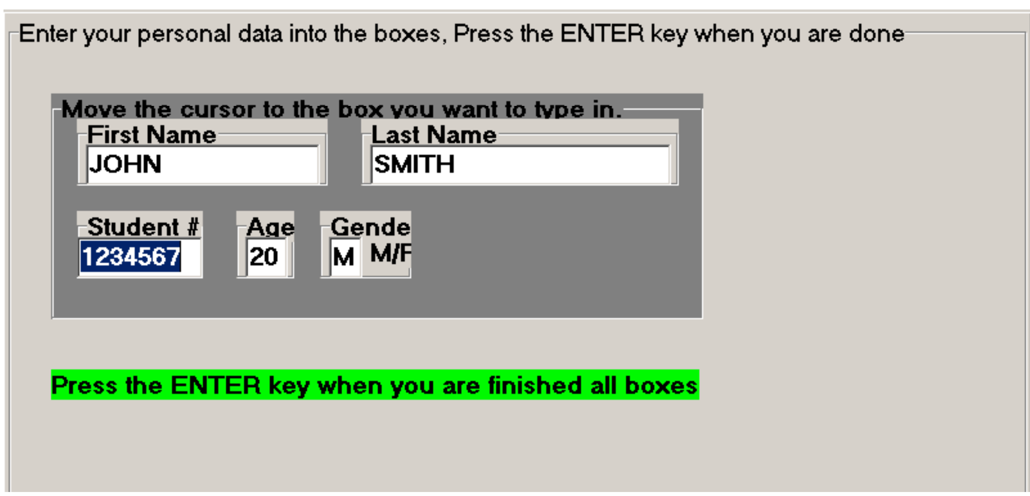

Figure G2. Participant identification screen.

Initial Instruction Screen

The instruction screen gives the participant general instructions for the current trial. In initial training instructions are displayed on how to drag triangles to targets, and descriptions of the two schedules are also given, each printed in the S^D hue. In later training trials, instructions are given to press the 'T' key whenever a CDS number match is available. An instruction page of this second kind is shown in Figure G3.

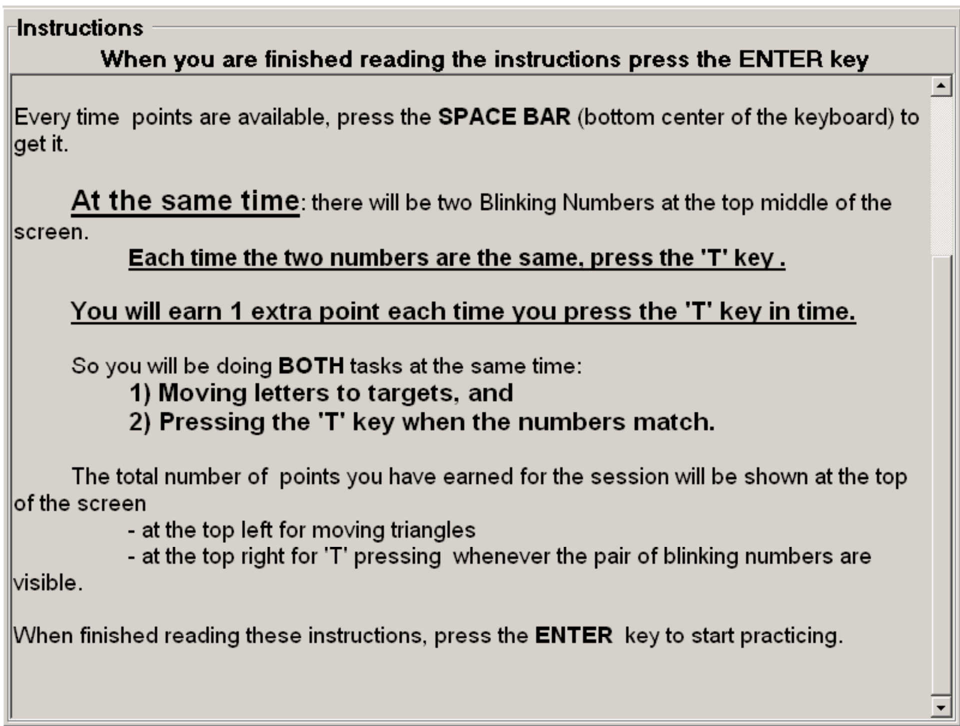

Figure G3. Instruction screen for sorting with CDT.

Sorting Screen during Training

During a training trial, the screen appears generally as shown in Figure G4. This screen displays instructions, in this case for performing the CDT along with sorting. The Figure G4 screen image is displayed at a moment when the two CDS numbers are equal but the participant has not yet pressed the "T" key. The total points accumulated from sorting are displayed at the top left of the screen, and from

"T" pressing (if available) at the top right of the screen. Note that a description of the current DRL 5-s contingency also appears at the bottom of the screen.

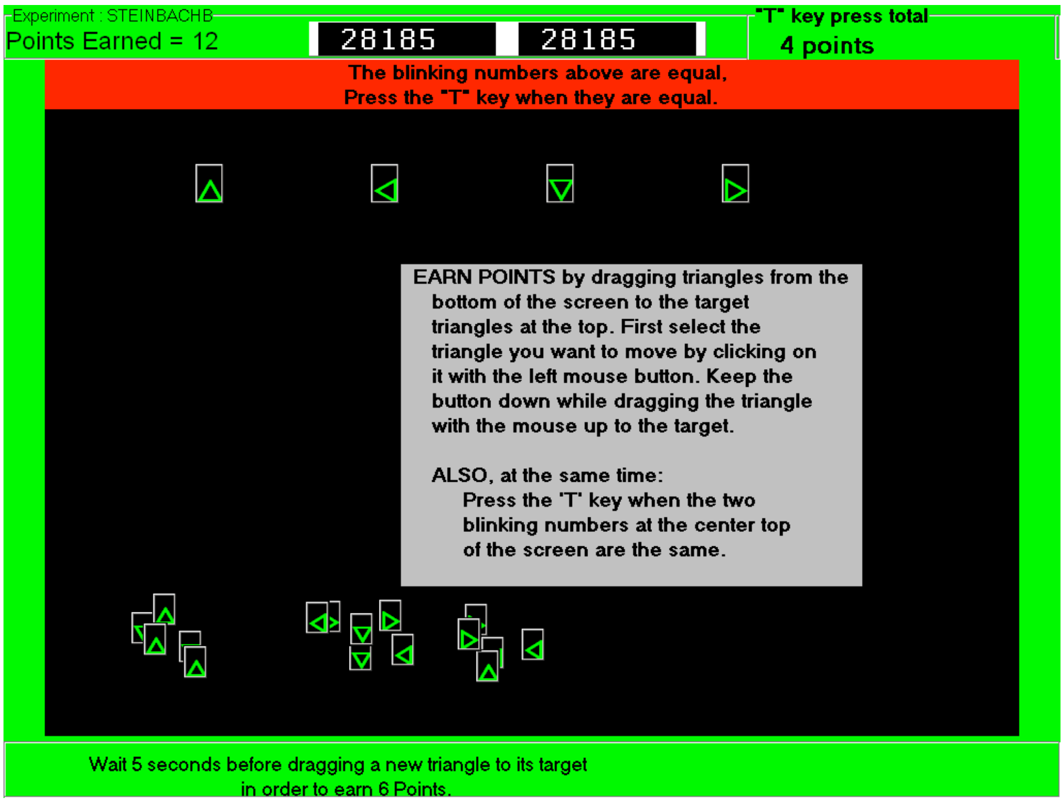

Figure G4. Training screen showing instructions. Sorting point total is a the top left, "T" press total at the top right, and the two CDS numbers at the top centre of the screen.