Fluency and Controlled-Operant Training Methods

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Table of Contents

List of Figures

List of Tables

Fluency and Controlled-Operant Training Methods

Numerous criticisms of the US educational system cite evidence of poor basic

skills and blame the lack of practice by students for these educational problems (Binder,

1993; Johnson & Layng, 1992; Miller & Heward, 1992; Wingert, 1996). Some of these

same authors have identified a solution to these problems: the use of behavioral

instructional and training techniques (Binder, 1993; Johnson & Layng, 1992; Beck &

Clement, 1991). These techniques, which can be traced back to the applications of early

behaviorists, such as Skinner's (1968) Programmed Instruction (PI) and Keller's (1968)

Personalized System of Instruction (PSI), evolved from basic behavioral research on

learning. Thus, they share many of the same features, such as breaking training material

into small units, requiring mastery before students can move on to the next unit, allowing

students to work at their own pace, and providing immediate feedback on test

performance.

Most applications of behavioral principles have used accuracy, i.e., percentage

correct scores, as a measure of performance or learning. This surprises some educators,

because they claim that most of the major discoveries made by Skinner and his

behavioral colleagues involved response rates as a standard measure of behavior (Binder,

1993). One behavioral training technique, Precision Teaching (PT), therefore,

reintroduced the use of rate or frequency as a measure of performance (Lindsley, 1990).

Lindsley argued that the addition of frequency measures provides a more sensitive

method for assessing behavior. Accuracy measures impose a ceiling upon students'

performance where all students who complete a task with 100% accuracy are classified as being equally skilled. Rate measures, however, enable educators to distinguish between performances on the basis of how many tasks can be completed in a set amount of time. Students who complete a different number of tasks per unit of time are considered to have different levels of skills.

This stress on rate allowed Lindsley to emphasize training not only to accurate mastery levels, but also to fluency levels. In general terms, fluency has been defined as "…the fluid combination of accuracy plus speed that characterizes competent performance" (Binder, 1988, 1993, 1996). This emphasis on speed, which is also found in the overlearning and automaticity literature (Dougherty & Johnston, 1996), has been shown to produce various behavioral outcomes, such as improved retention, endurance, and the ability to apply the learned skills to more complex tasks (Binder, 1996; Johnson and Layng, 1994, 1996). Another important implication of fluency was suggested by Haughton (1972, as cited in Binder, 1996), who states that fluency on elementary or component skills was a prerequisite for fluency on advanced or composite skills. Haughton found that traditional reinforcement techniques failed to increase the frequency of composite behaviors when students were not fluent on component behaviors. Therefore, fluency on elementary skills served as a prerequisite for learning more complex skills (Binder, 1996).

Definitions of fluency have evolved to incorporate these behavioral outcomes. Johnson and Layng (1996), for instance, elaborated on Haughton's work to describe the

RESAA standard, which specifies the functional criteria used to determine if certain skills or behaviors are fluent. The acronym stands for Retention, Endurance, Stability, Application and Adduction. Retention refers to a student's ability to maintain accuracy and rate of responding over an extended period of no practice. Endurance requires that a student be able to perform a skill at a rate criterion for time periods that are longer than the normal timings used in practice. Stability refers to a student's ability to engage in trained behavior in the face of distraction. Student should be able to apply (application) the learned skills to more complex tasks, and finally, they should show increasing capacity to learn new untaught skills instantly and without help, a process that has been referred to as contingency adduction (Andronis, Layng, & Goldiamond, 1998; Johnson & Layng, 1996). These functional criteria represent an important step towards defining fluency objectively.

Recent behavioral training models, such as the Morningside Model of Generative Instruction (Johnson & Layng, 1994), have combined the best features of PI, PSI and PT into one model, with an emphasis on high rates of responding and fluency. Literature in this area has spurred discussion and generated procedures to develop fluency. Some of these procedures, however, are open to further elaboration and experimentation.

Fluency procedures

In a series of recent publications, Binder (1996), Lindsley (1996a), and Johnson and Layng (1996) discussed the advantages of fluency measures. They trace the origins of fluency to the methodology of free-operant conditioning and extol the benefits of free-

operant methods. These methods are contrasted with controlled-operant or discrete-trials methods. Ferster (1953) initially distinguished between methods that allowed learners to respond more than once to each discriminative stimulus, the free-operant, from those that require a single response to each stimulus, the controlled-operant. For example in mathematics, free-operant training might involve writing the same math fact repeatedly but a controlled-operant procedure might present a series of math problems, requiring an answer to each problem.

Even though this basic distinction may still be pertinent to educational tasks (Lindsley, 1996), other methods for presenting these tasks have evolved. For example, Lindsley, a long time advocate of free-operant methods, encourages the use of a procedure called "Say All Fast A Minute Each Day Shuffled" or SAFMEDS. SAFMEDS involves using flash cards for practicing learning material to fluency. Students read all the cards out loud, fast, every day a minute at a time, and then shuffle them between sessions. This method fits Ferster's (1953) definition of the controlled-operant. Similarly, Johnson and Layng (1996) suggest that "most real-world examples of free-operant performance retain the feature of free responding, but with each response comes a new or different discriminative stimulus" (p. 282). According to Johnson and Layng, the critical problem with controlled-operant procedures, which they redefine as discrete trial procedures, is that the experimenter controls the time between presentations of the discriminative stimuli (S^D). This would typically hinder the student from achieving high rates, a prerequisite for achieving fluency.

A consideration of these distinctions between free-operant and controlled-operant procedures yields a number of methods for presenting tasks to students, all of which allow one response to each S^D. The difference between approaches is how trials (i.e., presentations of a new S^D) are separated. One approach, which has been called a free-operant, though technically it is not, presents multiple trials concurrently in a single workspace with no experimenter imposed inter-trial intervals (ITIs). For example, a sheet of paper or a computer screen with multiple math problems is presented to the student. A second approach presents one trial at a time, requires a response before presentation of the next trial, and imposes an ITI between trials. ITIs can vary from those that are long enough to decrease the rate of subject's responding, to minimum or 0 s ITIs programmed so that even the fastest subject does not have to wait to respond to each trial.

Although none of these procedures meet the definition of the free-operant, Binder (1996), Lindsley (1996), and Johnson & Layng (1996) all advocated procedures that they identify with the free-operant. The defining feature of these procedures seems to be the removal of experimenter or teacher control over the presentation of trials. They recommend using either flash-card procedures (SAFMEDS) that the students manipulate themselves or a procedure that presents multiple tasks on a single sheet of paper. Their rational for this preference is that experimenter or teacher controlled presentation of trials may impose ceilings on the subjects' performance. When teacher or experimenter controlled presentations are slow enough to impose time restrictions, then the amount a

student can practice per unit of time might be effected. Thus, given that learning is directly related to practice (LaBerge & Samuels, 1974; Stevens & Savin, 1962) methods that impose time restrictions will be less effective than those that do not.

It is unclear, however, whether presenting tasks or trials one at a time necessarily imposes ceilings upon performance. When the teaching materials and equipment used are sophisticated enough to allow changes of the discriminative stimuli that are rapid enough to be faster than any subject could possibly respond, the trial procedures should not slow learners' performance. Consequently it may not be the trial procedure per se that causes the ceiling effects, but rather the inadequacy of teaching equipment or techniques (e.g., slow computers, inadequate software, or manually-controlled trials) that increases ITIs and decreases time on task.

It is surprising that in spite of extensive discussions favoring training methods where experimenter imposed time constraints are eliminated, their effectiveness over other methods has never been tested systematically. In view of the rapid developments in computer technology (advanced hardware and software), it would be unwise to exclude some variations of controlled-operant training methods unless data from carefully implemented experiments suggest that they are not adequate. Thus, the purpose of this study was to evaluate the difference between various methods for presenting learning tasks to subjects with regard to their effectiveness for establishing fluent behavior. Specifically, this study compared the effects of three task-presentation procedures on three main fluency outcomes, retention, application, and adduction. One procedure, called No ITIs, will present multiple

tasks simultaneously on a computer screen after subjects have demonstrated accurate responding to individually-presented tasks. Subjects will be trained using this presentation mode until they reach a rate criterion that has been correlated with retention and application. Munson (1998) tested terminal rate-training rates of 25, 30, 35, and 40 responses per minute and found that all but the first one (25) predicted acceptable performance on tests of retention, endurance, stability, and application. Therefore, the rate of 30 responses per minute was selected as a rate criterion in this experiment. A second procedure, called 0s ITIs, will present individual tasks with a zero second ITI after subjects have demonstrated accurate responding. Subjects will be trained using 0s ITIs until they reach the rate criterion used with the first procedure. The third procedure, called 1.5s ITIs, is similar to the second, but will impose a long enough ITI between tasks to effectively slow responding of all subjects. Subjects will be trained using 1.5s ITIs until a criterion for the number of tasks completed correctly is reached. The criterion number of tasks will equal the number of tasks required by subjects using the 0s ITIs procedure to reach the rate criterion. These three procedures manipulate elements of experimenter imposed delays between trials that have been hypothesized to affect performance.

<div align="center">Method</div>

Subjects

Thirty-one West Virginia University undergraduates served as subjects. They were recruited through an advertisement (see Appendix A) posted on the Psychology Department's subject recruitment board. The subjects were randomly selected from those

who signed up for the experiment. Potential subjects were given a short paper and pencil

test consisting of translating 10 binary numbers into decimal equivalent (see Appendix

B). None of the subjects responded accurately to any of the binary numbers on the

subject selection test. All subjects had completed either College Algebra (Math 3) or

Finite Mathematics (Math 28) and were not Computer Science majors. Subjects were

randomly assigned to experimental conditions and were asked to participate four to five

days a week for one hour each day. All subjects were required to read and sign an

Informed Consent Form prior to their participation (see Appendix C and Appendix D).

One of 31 subjects failed to show acceptable progress during training, and was therefore

excused from the study.

Settings and apparatus

Experimental sessions were conducted in 2.2m by 1.8m room equipped with a

table, a chair and the apparatus. Experiment sessions were run on an Intel-based 486

microcomputer running at 33 MHz with 8 MB of random access memory (RAM), a 14"

color SVGA computer monitor, and a keyboard. The computer programs that controlled

experimental sessions were programmed in MS-DOS® versions of the Turbo Pascal and

C programming languages. The computer was used to control experimental sessions and

collect data. The subjects made their responses through a microphone with

noise-canceling and directional audio properties (Shure microphone, model SM-10A),

that was connected to the computer's motherboard by an IBM Multimedia Audio

Capture and Playback Adapter (M-ACPA) audio board.

Voice recognition. Dragon Systems' Developers Tool Kit voice recognition software was used. This software can be programmed to accompany any C or C++ computer program. When subjects emit a vocal utterance above 25 dB, the computer system receives an analog signal from the microphone, converts it to digital format in the M-ACPA audio board, and sends a digital signal to a memory-resident speech driver. The speech driver compares the digitized pattern with word patterns stored in memory from a particular vocabulary of utterances sampled from the subject, then sends a representation of the word spoken (if recognized) to the main program running the experiment. The digitized patterns are sent to the speech driver throughout an utterance so that processing and recognition can occur simultaneously without waiting for the end of an utterance. The speech driver requires a minimum of 100 ms between utterances. This procedure allowed voice input to be treated similarly to keyboard input without appreciably slowing down the main computer program.

Calibration. The Dragon System speech driver was trained to recognize (digitize) speech from each individual subject by having subjects repeat each word to be used. A 54 word vocabulary was trained, i.e., the words "zero" through "fifty-one" "stop" and "go". The speech driver's confidence level was also used to calibrate the voice recognition equipment. Subjects repeated each word a minimum of three times or until the speech driver's confidence level was above 90 % for three consecutive utterances. The calibration took 5-10 minutes to complete, and ensured the accuracy of the voice recognition apparatus. In addition, for increased accuracy of the voice recognition

apparatus subjects re-calibrated the speech driver before each experimental session by saying each word in the vocabulary at least once or until the speech driver's confidence level was above 90%.

General outline of experiment

The experimental phases are shown in Table 1. After pre-training and the first test, all subjects were trained to translate binary numbers to decimal numbers to at least 85% accuracy (Howell & Lorson-Howell, 1990) using the same computer based training. After a second test, the three different methods under investigation were used to provide subjects with additional practice. Subsequent tests occurred immediately after subjects had met rate or practice criteria and after two weeks without practice.

Procedures

Testing. All eligible subjects were tested four times during the study. The first test was administered after subjects had completed pre-training, the second test was administered after they completed accuracy training, the third was administered at the completion of rate training, and the fourth about two weeks after training. All test versions were equivalent, i.e., the problems required the same computational skills, but were different in terms of the order of binary used. Prior to the administration of the first test, the following instructions were delivered verbally by the experimenter: "You will now be tested on what you already know about binary numbers. Read the instructions on the screen carefully and the say "go" when you are ready. Try to answer as many questions as you can from each of the six testing screens, using what you have already

Table 1

Experimental Phases for All Training Conditions and All Subjects in the Experiment.

Experimental phases
I.   Subject Selection Test
II. Pre-training
III. Testing: Pretest
IV. Training: to 85% accuracy
V. Testing: Post Accuracy
VI. Rate Training or Practice (0s ITIs; 1.5s ITIs; or No ITIs)
VII. Testing: Post Rate
VIII. Testing: Retention

learned. You may not be able to answer many of the questions, but try your best".

Identical verbal instructions were delivered prior to administration of all tests with the

exception of the last sentence. The first test (after pre- and vocabulary training) was

administered towards the end of the first experimental session. All other tests were given

at the beginning of a session, i.e., subject would reach a criterion, the session was

terminated, and a test administered at the beginning of next session.

Three types of tasks were tested on each of the four tests, using two different

methods of presenting the problems on the screen, a Trial method and a Multi-trial

method. Therefore, each test consisted of 6 different sections (3 types of tasks by 2

modes of screen presentation). The Trial method for presenting the testing material

presented one stimulus on the screen at a time with the next stimulus presented after a

response was made with a 0s ITI. The Multi-trial method presented 50 stimuli on the

screen at a time and subjects proceeded by responding from left to right, as if reading a

book. The order in which these methods were used was counterbalanced across subjects.

The first task subjects completed involved translating the five digit binary

numbers that they learned during training. They were required to translate the binary

numbers into decimal numbers (0-31) in a one-minute timing. When the Trial

presentation mode was used, subjects received the following instructions before being

presented with the test: "Your task is to translate a series of 5-digit BINARY numbers

into DECIMAL numbers as FAST as you can. You will have ONE MINUTE to do so.

The numbers will be presented on the screen ONE AT A TIME. For example, if you see

'00000', you should say 'zero'. Please say the word 'GO' to start". When Multi-trial

presentations were used, subjects were presented with different instructions prior to

being tested: "Your task is to translate a series of 5-digit BINARY numbers into

DECIMAL numbers as FAST as you can. You will have ONE MINUTE to do so.

FIFTY numbers will be presented on the screen at a time. Translate them from left to

right, as if reading a book. The number you are working on will be presented in WHITE.

For example, if you see '00000', you should say 'zero'. Please say the word 'GO' to start".

The second task required subjects to translate six digit binary numbers that they

had not been trained to translate into the decimal numbers 32 to 51 in one-minute

timings. When the Trial presentation mode was used, subjects received the instructions:

"Your task is to translate a series of SIX-digit BINARY numbers into DECIMAL

numbers as FAST as you can. You will have ONE MINUTE to do so. The numbers will

be presented on the screen ONE AT A TIME. For example, if you see '000000', you

should say 'zero'. Please say the word 'GO' to start." Before the Multi-trial presentation

mode, subjects received the same instructions except the sentences: "FIFTY numbers will

be presented on the screen at a time. Translate them from left to right, as if reading a

book. The number you are working on will be presented in WHITE." was substituted for

the sentence: "The numbers will be presented on the screen ONE AT A TIME."

Third, subjects were required to solve simple arithmetic problems presented in

five digit binary numbers, giving the answers in decimal numbers (0-51), in one-minute

timings. Before the Trial presentation mode was used, subjects were presented with the

following instructions: "Your task is to solve a series of MATH PROBLEMS presented in BINARY numbers and give the answer in DECIMAL numbers. Do this as FAST as you can. You will have ONE MINUTE. The problems will be presented on the screen ONE AT A TIME. Some of the problems involve ADDITION and some SUBTRACTION. For example, if you see '00001+00001', you should say 'two'. Or, if you see '00010-00001', you should say 'one'. Please say the word 'GO' to start". Prior to the Multi-trial presentation mode the same instructions were read to subjects, except that the sentence: "The problems will be presented on the screen ONE AT A TIME" was replaced by the following: "FIFTY problems will be presented on the screen at a time. Proceed from left to right, as if reading a book. The problem you are working on will be presented in WHITE." Only 49 math problems, not 50, were presented on the screen, but for simplification purposes the subject instructions were kept simple and as similar to the instructions for the other testing tasks as possible.

Subjects were presented with these six testing tasks sequentially and data were collected on accuracy of responding (% correct), latency of responding to each question, and rate of responding.

Pre-training. The experimenter read the following instructions to all subjects: "During this experiment you will be trained to recognize and translate binary numbers into decimal numbers, both accurately and fast. Between training phases, you will be tested on your performance. Most training and testing will be conducted on a computer. For training and testing you will be presented with binary numbers on the computer

screen. Before each training or testing phase, you will also be presented with specific

instruction about what is expected of you. Read the instruction carefully and ask the

experimenter if something is unclear. In general, your task will be to translate the binary

numbers into their decimal equivalents. For each correct translation, i.e., each correct

response you make, you will get one point and you will accumulate these points

throughout the experiment. Each point is worth one half cent. You will earn the most

money by responding accurately and fast. The more accurate you are and the faster you

go, the more money you will earn. Remember, that there is no penalty for incorrect

answers, so guessing may be appropriate in some cases". Then, subjects read a short

paper and pencil program explaining how to translate binary numbers into decimal

numbers (see Appendix E). Prior to going through the program the following

instructions were delivered verbally by the experimenter: "Now you will go through

instructions explaining how to translate binary into decimal numbers. Read the

instruction carefully and answer the questions being asked. The correct answers are

provided (experimenter points), but do not check them until you have tried yourself;

cover the answers with a piece of paper. At the end of the instructions you will be asked

to translate a few binary numbers into decimals. Check your answers with the

experimenter". The final question of the program asked subjects to translate 5 binary

numbers to decimal numbers. If they failed to translate all five correctly, they were asked

to read through the instruction again and answer the questions that they missed on their

previous attempt. All subjects translated all five binary number correctly by the second attempt.

Vocabulary Training. Following pre-training of binary numbers the speech-driver was calibrated (as described previously). The experimenter read the following instructions: "Now the computer has to be trained to recognize your speech. A vocabulary of 52 numbers and 2 words will be trained. This will take approximately 15 minutes and requires you to repeat the same word a number of times. The first words you may have to repeat very often but as the computer starts recognizing your speech, fewer repetitions are needed. Be careful to say only the word the computer asks for. After training, your vocabulary will be re-calibrated by having you go once more through it; usually only once per each word."

Accuracy training. Following pre-training and vocabulary training (calibration), subjects read the following instructions presented on the computer monitor: "Your task is to translate a series of BINARY numbers into DECIMAL numbers and SAY the answer. If your answer is CORRECT you will hear a HIGH tone and a point will be added to your score. If your answer is INCORRECT you will hear a LOW tone and you will be asked to try again. If you answer incorrectly for the second time, the correct answer will be given. No points will be given for incorrect answers nor correct second attempts. For example, if you see '00000', you should say 'ZERO'. Please say the word 'GO' to start". The binary numbers were presented in a random sequence, one at a time, centered on the computer monitor. Subjects responded by saying the corresponding decimal number to

each binary number. Subjects received feedback after each response. If a response was correct, i.e., the word spoken by the subject matched the decimal equivalent of the binary number on the screen, a 200 Hz tone was sounded and a point was added to a point counter displayed on the screen and the next trial appeared immediately on the screen. If the response was incorrect, i.e., the vocal utterance did not match the decimal equivalent of the binary number, a computerized 800 Hz tone, and the message, "Incorrect, please try again" occurred. The feedback for correct and incorrect responses during correction trials was the same as during the first presentation, but subjects did not gain points for correct answers. In addition, if subjects respond incorrectly to a correction trial the statement "Incorrect. The correct answer was XX." was flashed on the center of the screen above the target stimulus for two seconds, after which the next binary number was presented.

Subjects responded to three blocks of 20 trials, receiving feedback on their accuracy after each block of trials. All subjects achieved 85% accuracy by the third block of 20 trials, after which they received the second test.

Condition I: 0s ITIs. Before undergoing pre-training 10 subjects were randomly selected from a pool of 30 subjects to receive Condition I, 0s ITI's training. Subjects received pre-training and accuracy training and then, before initiating rate training, the experimenter read the following instructions: "During this training phase you will be trained to translate binary numbers accurately and fast in 1-minute timings. Read the instructions carefully and let the experimenter know if you have any questions. If the

feedback at the end of each timing tells you to be faster or more accurate or both, press

F3 and ENTER to start the next session. Otherwise, call the experimenter.

REMEMBER, that the faster you go and the more accurate you are, the more you will

earn". These instructions were consistent across all conditions of the experiment. Then

the subjects were presented with the following instructions on the computer monitor:

"You will now be presented with a series of BINARY numbers. Your task is to translate

them into DECIMAL numbers and SAY the answer as FAST as you can without losing

ACCURACY. You will have ONE MINUTE to do so. Each correct answer is worth

ONE POINT. However, you will only receive feedback on your performance at the end

of each ONE-MINUTE timing. For example, if you see '00000', you should say 'ZERO'.

Please say the word 'GO' to start". Subjects were exposed to series of 1 minute-timings

in which feedback for each trial was removed. After each response a 0 s ITI was

programmed. At the end of the one-minute timing, subjects received feedback on the

number of trials attempted, number of correct responses, number of incorrect responses,

percentage of correct responses, and the number of total points accumulated throughout

the experiment. One-minute timings continued until subjects reached a rate of 30 correct

responses per minute for two one-minute timings while maintaining 85% accuracy.

These criteria have been correlated with retention and application of binary numbers that

reflects fluent performance (Munson, 1998).

Additional feedback was provided after each timing dependent on subject's

performance. If subjects maintained 85% accuracy, but had not reached the rate

19

criterion, the instructions "You need to be faster. Try again." appeared in the middle of the screen. If subjects reached the rate criterion, but were below 85% accuracy, the instructions "You need to be more accurate. Try Again." appeared on the screen. When rate of responding was below the rate criterion and accuracy was less than 85%, the instruction "You have to go faster and be more accurate." appeared on the screen. When subjects responded with 85% accuracy or better and above rate criterion for the first time, they received the message "Well done! Please get the experimenter". They were then told that "You are doing very well, but you still have to go through a few more timings". After the second timing that subjects met both rate and accuracy criteria, training was completed and subjects were tested for the third time.

Condition II: 1.5s ITIs. The rate-training procedure and instructions were exactly the same as in Condition I with the addition of 1.5s blackout interval between trials. The number of trials subjects completed was yoked to the number of trials needed to reach the rate criterion for subjects in the 0s ITIs training condition. Yoking was accomplished by the following procedures: A subject was randomly selected from the subject pool, assigned to the 1.5s ITIs condition, and yoked to a subject in the 0s ITIs condition. At the end of each one-minute timing subjects received feedback on their accuracy. When their accuracy was above the 85% criterion they received the following instruction "Well done. Try again". However, if accuracy fell below 85%, subjects received the instruction "You need to be more accurate. Try again". When subjects had completed the predetermined (yoked) number of trials, the message "Well done! Please get the

experimenter" was flashed on the screen and the one-minute timing was terminated. Subjects were then tested for the third time.

Condition III: No ITIs. Before undergoing pre-training 10 subjects were randomly selected from a pool of 30 subjects to receive No ITI's training. Subjects received the same pre-training and accuracy training as in first two training conditions, 0s and 1.5s ITIs. Then, before initiating rate training the following instructions were presented on the computer monitor: "You will now be presented with 50 BINARY numbers on the computer monitor before you. Your task is to translate them into DECIMAL numbers and SAY the answer as FAST as you can without losing ACCURACY. You will have ONE MINUTE to do so. Each correct answer is worth ONE POINT. However, you will only receive feedback on your performance at the end of each ONE-MINUTE timing. Proceed by translating numbers from left to right as if reading a book. The number you are working on will be presented in WHITE. For example, if you see '00000', you should say 'ZERO'. Please say the word 'GO' to start". Fifty binary numbers then appeared on the computer screen at a time. Subjects responded to as many of the problems on the computer screen as possible in one minute. Responses were made in the same way as in the other training conditions. After each one-minute timing, subjects received feedback on the accuracy and rate of their performance, as in 0s ITIs training. Training proceeded until rate of 30 responses per minute and 85% accuracy criteria were met, after which subjects were tested.

Payment Contingencies. Subjects earned half a cent per each correct response during accuracy training, rate training, and testing. In addition to performance based earnings, subjects earned an attendance bonus of $6 for not missing any sessions without notifying the experimenter. If subjects failed to attend a scheduled appointment without notifying the experimenter in advance, they lost their attendance bonus. Subjects were also eligible to earn bonus points for courses that allowed credit for participation in research. All earnings were paid at the end of subjects' participation.

Results

Pre-training

All subjects completed the programmed instruction on binary numbers within 20 minutes. No subject made an error on the first four frames of the program. Seven subjects made errors on the final frame, which involved translating five binary numbers into decimals. Six subjects made one error and one made two errors. All subjects corrected the errors on their second attempt to achieve 100% accuracy on the final question. Two of these subjects were in the 0s ITIs group, and five in 1.5s ITIs group, including the one that made two errors. None of the subjects in the No ITIs group made an error during the pretest. Most errors were simple addition or multiplication errors that were quickly resolved.

Accuracy training

All thirty subjects achieved 85% accuracy or better by their third block of accuracy training trials and the average accuracy across subjects was 90, 96, and 96 %

for the first, second and third blocks of trials, respectively. There were no differences in performance between conditions for any of the three accuracy training blocks, $\underline{F}$ (2, 27) = 1.22, $\underline{p}$ > .05, $\underline{F}$ (2, 27) = .927, $\underline{p}$ > .05, and $\underline{F}$ (2, 27) = .339, $\underline{p}$ > .05 for blocks one, two and three, respectively.

Rate Training

As can be seen in the top panel of Table 2, subjects who received No ITIs training spent less time in rate training than subjects who were trained using 0s and 1.5s ITIs, with an average of 29 one-minute timings needed to reach criterion. Subjects who received 0s ITIs training also spent less time in rate training, 60 one-minute timings, than the 1.5s ITIs subjects, who went through 94 one-minute timings. A Scheffe test with an alpha level of .05 was use for post hoc comparisons. The test showed that these differences were significant, $\underline{F}$ (2, 27) = 16.21, $\underline{p}$ < .0001. The average number of trials required to achieve rate criterion was also significantly higher for the 0 and 1.5s ITIs conditions when compared to the No ITIs, or 1423, 1422 and 696 trials, respectively ($\underline{F}$ (2,27) = 6.83, $\underline{p}$ = .004). There was no difference between 0s and 1.5s ITIs subjects. Differences in the accuracy of responding were not significant between conditions ($\underline{F}$ (2, 27) = 1.90, $\underline{p}$ > .05) with an average accuracy of 91% for 0s ITIs, 91% for 1.5s ITIs and 94% No ITIs. Consistent with the differences in total numbers of trials to criteria, subjects who received ITI training (0s and 1.5s ITIs), also made significantly more correct responses than subjects who received No ITIs training, $\underline{F}$ (2,27) = 6.36, $\underline{p}$ = .0054 and more incorrect responses, $\underline{F}$ (2,27) = 5.11, $\underline{p}$ = .013. The 0s ITIs subjects made an

average of 1314 correct and 108 incorrect responses and the 1.5s ITIs subjects made

1306 correct and 112 incorrect responses on the average, whereas the No ITIs subjects

made an average of 652 correct and 44 incorrect responses.

Analyses of responding per one-minute timing during rate training are presented

in the middle panel of Table 2. Even though the accuracy of responding was similar

across conditions, the 1.5s ITIs subjects made fewer correct responses per one-minute

timing than subjects undergoing 0s ITIs and No ITIs training, an average of 14 versus 22

and 23 (F (2,27) = 81.47, p < .001). Subjects in general made very few incorrect

responses and there were no differences between groups, F (2,27) = 2.25, p > .05. The

total number of responses per one-minute timing was also lower for subjects undergoing

1.5s ITIs training than for subjects undergoing 0s and No ITIs training, an average of 15

versus 24 and 25, F (2,27) = 112.47, p < .001. The average rate of responding over the

last five one-minute timings was also significantly lower for subjects who underwent

1.5s ITI training than for the 0s and No ITI training subjects, 171 responses versus 29

responses per minute for both the 0s and No ITIs groups, (F (2,27) = 304.89, p < .001).

The bottom panel of Table 2 presents other rate training data of interest. There were no

differences between the three conditions with respect to the confidence of the computer

recognizing the subjects' utterances (F (2, 27) = 1.78, p > .05), nor were there any

---

[1] Because subjects in the 1.5s ITIs training condition were yoked to subjects in the 0s ITIs condition, they were stopped without completing the last one-minute timing if they had met their practice criterion. Therefore, the last one-minute timing was not used in calculating the average rate of the last five timings for these subjects.

Table 2

Mean Performance Scores of Subjects in All Training Conditions During Rate Training.

Standard deviations are presented within parenthesis.

	# of 1-min timings	# of trials (%)	Accuracy trials	# of correct trials	# of incorrect
Os ITIs	60 (24)	1423 (582)	91 (3.6)	1314 (545)	108 (61)
1.5s ITIs	94 (33)	1422 (575)	91 (4.1)	1306 (541)	112 (62)
No ITIs	29 (14)	696 (320)	94 (3.1)	625 (297)	44 (31)

	Correct trials per timing	Incorrect tr. per timing	Trials per timing	Rate: Last 5 timings
Os ITIs	22 (1.4)	2 (0.6)	24 (1.2)	29 (1.7)
1.5s ITIs	14 (0.8)	1 (0.6)	15 (0.9)	17 (1.2)
No ITIs	23 (2.6)	1 (0.7)	25 (2.3)	29 (0.8)

	Confidence of recognition	Latency of responding	Duration of utterance
Os ITIs	90 (4.2)	1759 (141)	438 (109)
1.5s ITIs	87 (5.4)	1647 (205)	434 (59)
No ITIs	89 (3.2)	1662 (258)	505 (89)

differences in latency of responding (F (2, 27) = 0.87, p > .05) and utterance duration (F (2, 27) = 2.04, p > .05).

Figure 1 captures the primary similarities and differences between training conditions. It shows the change in rate of correct and incorrect responding that occurs as a result of rate training for one representative subject from each of the three conditions. Subjects H07 and H30 were selected because their performance corresponds to closely to their respective the group averages. Subject h12 is shown because it was yoked to H07 for practice. A common characteristic was that the number of incorrect responses decreased slightly throughout training whereas the number of correct responses increases considerably. For the subjects who received 0s and No ITIs training (H07 and H30) the rate of responding increased until they reached the rate criterion. For subject H12, who underwent 1.5s ITIs training, the rate increased until about halfway through training and then it stabilized at a fairly constant rate of about 15 responses per minute. There were, however, two notable deviations from the terminal average rate for the H12 during sessions 73 and 98. The first instance was due to computer failure. In session 98 training was terminated about halfway through the last timing when the subject had responded to the same number of trials as H07. Figure 1 also shows that it took subject H30 (No ITIs) less time to reach the rate criterion than the subject trained with 0s ITIs. Additionally because H12 responded at a lower rate, it took her more sessions to complete the same number of trials as the subject in the 0s ITIs condition.

Figure 1. Correct and incorrect rate of responding per 1-minute timings as a function of

training (1-minute timings) for representative subjects, H07, H12, and H30, from each

training condition, 0s, 1.5s, and No ITIs. H12 was yoked to H07 for practice. The

circles represent correct responding and the triangles incorrect responding per 1-minute

timings.

Number of trials

0s ITIs: H07

1.5s ITIs: H12

No ITIs: H30

Rate criterion......

Correct trials
Incorrect trials
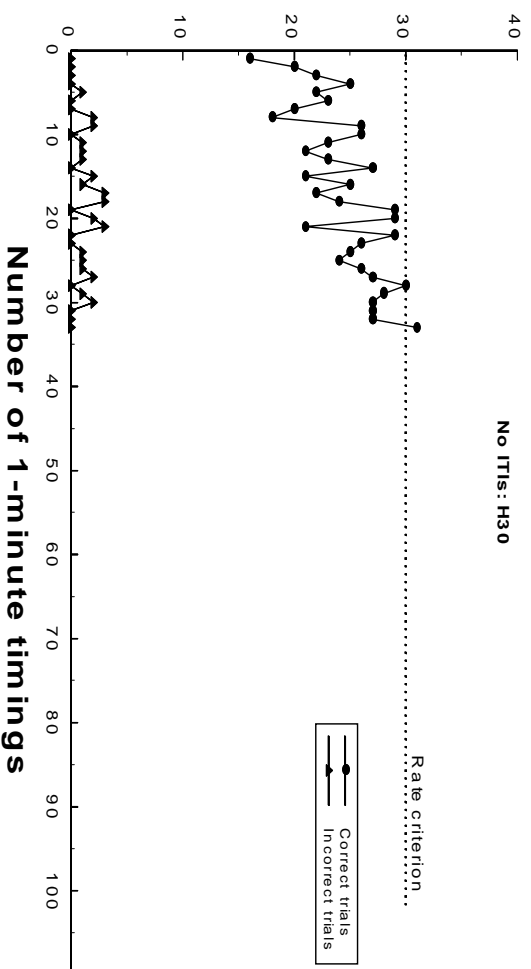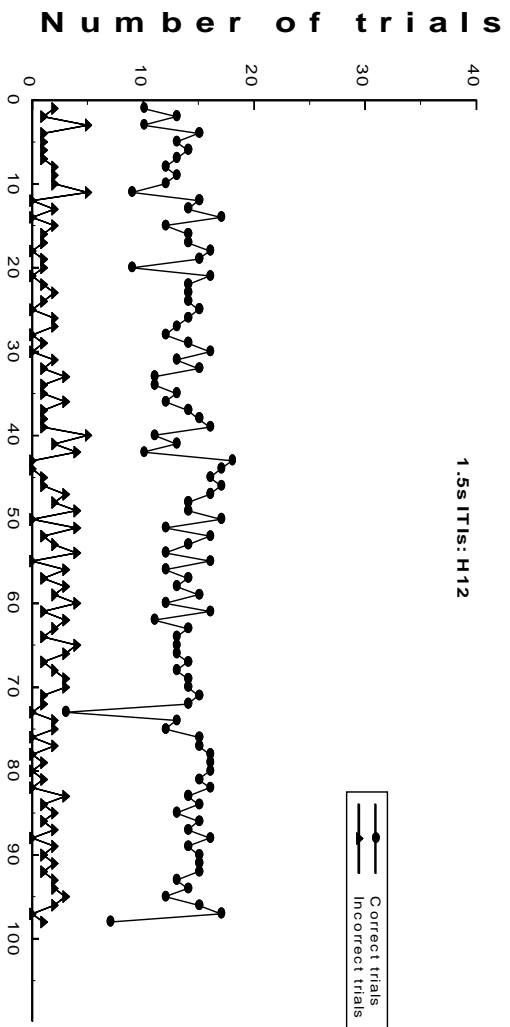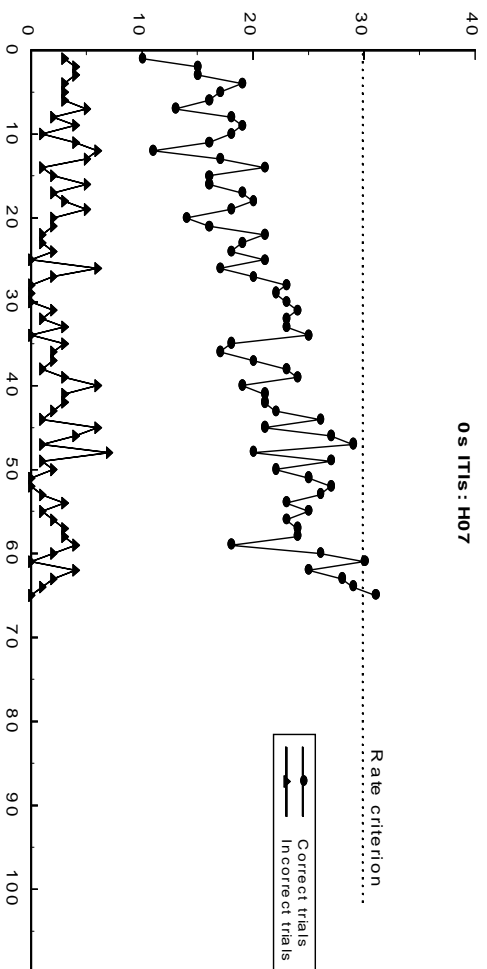
Number of 1-minute timings

Test performance

   Accuracy. There were no systematic differences between the three conditions on

any of the six testing components. In addition, there were no significant differences in

accuracy related to the order of Multi-trial and Trial methods of presentation. Therefore,

the data were collapsed across conditions and order of presentation methods. Figure 2

shows the mean percent accuracy for each of the six sub-components of each test

averaged across the three training conditions. The differences between the four testing

administrations were analyzed using t-tests for paired comparisons, an appropriate

statistic for within-subject comparisons. The increase in accuracy between the pretest

and the post-accuracy test was significant for each sub-component test. For

Trained:Trials the mean accuracy increased from 54% to 84%, t (28)= -4.83, p < .001.

For Trained: Multi-trials the mean accuracy increased from 58% to 91%, t (28)= -5.17, p

< .001. For Untrained: Trials the mean accuracy increased from 53% to 77%, t (28)= -

3.16, p < .001. For Untrained: Multi-trials the mean accuracy increased from 48% to

78%, t (28)= -4.07, p < .001. For Math: Trials the mean accuracy increased from 30% to

70%, t (28) = -5.18, p < .001. And For Math: Multi-trials the accuracy increased from

31% to 61%, t (27) = -3.50, p = .002. There also was a significant increase in accuracy

after rate training for two components, i.e., Trained: Trials and Math: Multi-trials, but it

did not change for the other four components. The increase for Trained: Trials was from

84% to 92%, t (28) = -2.11, p = .044, and the increase for Math: Multi-trials was from

61% to 80%, t (27) = -3.73, p = .001. Accuracy did not change for any of the six

Figure 2. Average accuracy of responding on all tasks across training conditions on

Pretests, Post Accuracy, Post Rate, and Retention tests. Circles represent Trials and

triangles represent Multi-trial presentation modes. The top panel shows trained binary

numbers, the middle panel shows untrained binary numbers, and the bottom shows math

problems presented in binary numbers.

Trained binary numbers

Untrained binary numbers

Math in binary numbers
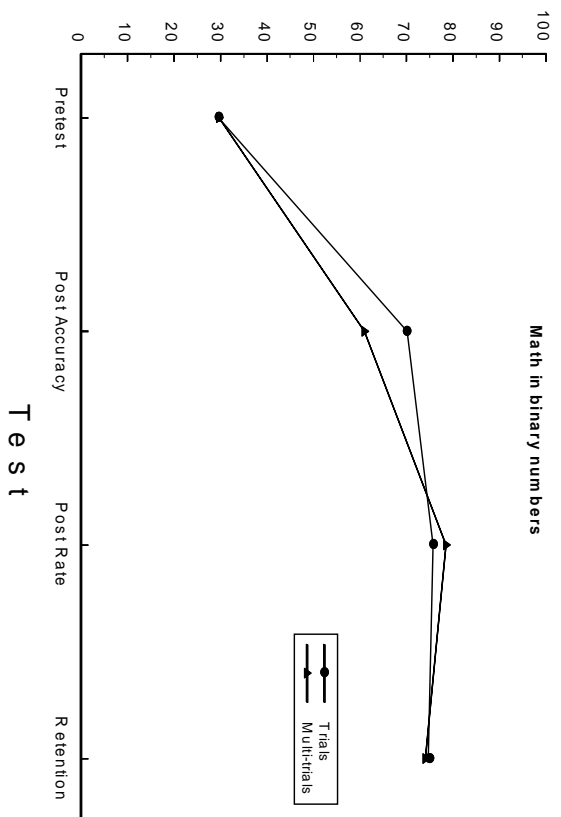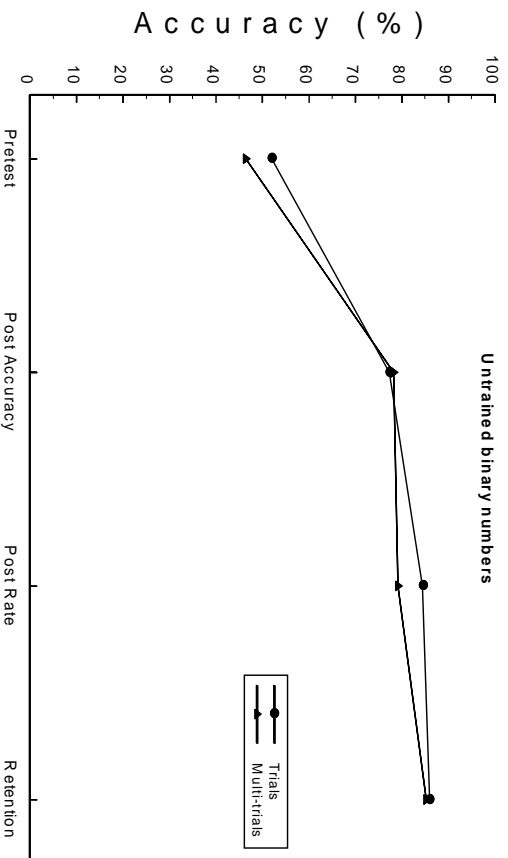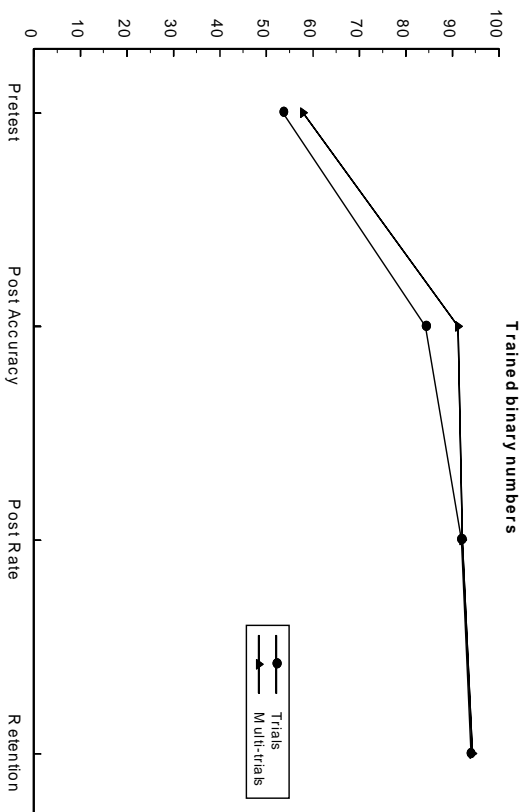
components between the completion of rate training and the retention test. No difference was found between Trial and Multi-trial presentations on any of the tests.

Tables 3 and 4 show a progressively decreasing trend in accuracy of responding across types of tasks. Subjects generally responded more accurately to trained binary numbers than to untrained. Also, they responded more accurately to untrained binary numbers than to math problems presented in binary. As there was no interaction between type of training and type of testing task, data were collapsed across conditions. A repeated measure ANOVA and paired sample t-tests were used for comparing the different types of tasks. The results of the ANOVAs and the simple t-test comparisons are also reported in Tables 3 and 4. They show that for seven of eight tests there were significant main effects for type of task. Seven of 12 simple comparisons were significant when presented as Trials, and nine of 12 for Multi-trial presentations.

Rate of correct responding. Figures 3, 4, and 5 show the average rate of correct responding for each sub-component of the tests plotted as a function of condition and training. As between-condition comparisons were planned and between subjects, differences at all tests were evaluated using t-tests for independent samples. Figure 3 represents testing on **trained binary numbers** using Trial and Multi-trial presentation modes. The top panel shows performance under the Trial presentation mode. When Trial presentations were used (top panel of Figure 3), 0s ITIs subjects responded correctly to significantly more trials than No ITIs subjects on both the Post Rate and the Retention tests ($\underline{t}$ (18) = 2.68, $\underline{p}$ = .015, $\underline{t}$ (18) = 3.06, $\underline{p}$ = .006). In

Table 3.

The Mean Accuracy (%) of Responding for All Subjects to Trained and Untrained Binary Numbers, and Math Problems in Binary on All Tests for Trial Presentations, Including Degrees of Freedom (Df) and F values for a Repeated Measures Analysis of Variance of the Three Tasks. The Lower Panel Shows Simple Comparisons Between Tasks at All Tests where T = Trained Trials, U = Untrained Trials, and M = Math Trials.

Type of Task	Test			
	Pretest	Post Acc.	Post Rate	Retention
Trial presentations:				
Trained	54	84	92	94
Untrained	51	77	84	86
Math	29	70	76	74
Df	(2, 58)	(2, 56)	(2, 56)	(2, 56)
$\underline{F}$	5.65**	2.44	5.37**	8.83**
Simple comparisons:				
	T > U	T > U	T > U	T > U*
	U > M*	U > M	U > M	U > M*
	T > M**	T > M*	T > M**	T > M**

* $\underline{p} < .05$

** $\underline{p} < .01$

Table 4.

The Mean Accuracy (%) of Responding for All Subjects to Trained and Untrained

Binary Numbers, and Math Problems in Binary on All Tests for Multi-trial Presentations,

Including Degrees of Freedom (Df) and F values for a Repeated Measures Analysis of

Variance of the Three Tasks. The Lower Panel Shows Simple Comparisons Between

Tasks at All Tests where T = Trained Trials, U = Untrained Trials, and M = Math Trials.

	Test			
Type of Task	Pretest	Post Acc.	Post Rate	Retention
Multi-trial presentations:				
Trained	58	91	92	94
Untrained	46	77	79	85
Math	30	61	79	74
Df	(2,58)	(2, 54)	(2, 56)	(2, 58)
F	5.67**	12,58**	4,84*	10.86**
Simple comparisons:				
	T > U	T > U**	T > U**	T > U**
	U > M	U > M*	U > M	U > M*
	T > M**	T > M**	T > M**	T > M**

* $p < .05$

** $p < .01$

 Figure 3. Average number of correct responses (trials) per minute to trained binary

numbers on Pretests, Post Accuracy, Post Rate, and Retention tests for the three training

methods. Black bars represent 0s ITIs training, gray bars represent 1.5s ITIs training and

white bars represent No ITIs training. The upper panel shows test results when Trial

presentations were used and the lower shows results for Multi-trial presentations. The

error bars represent standard deviation.

Trained binary numbers: Trials

Trained binary numbers: Multi Trials
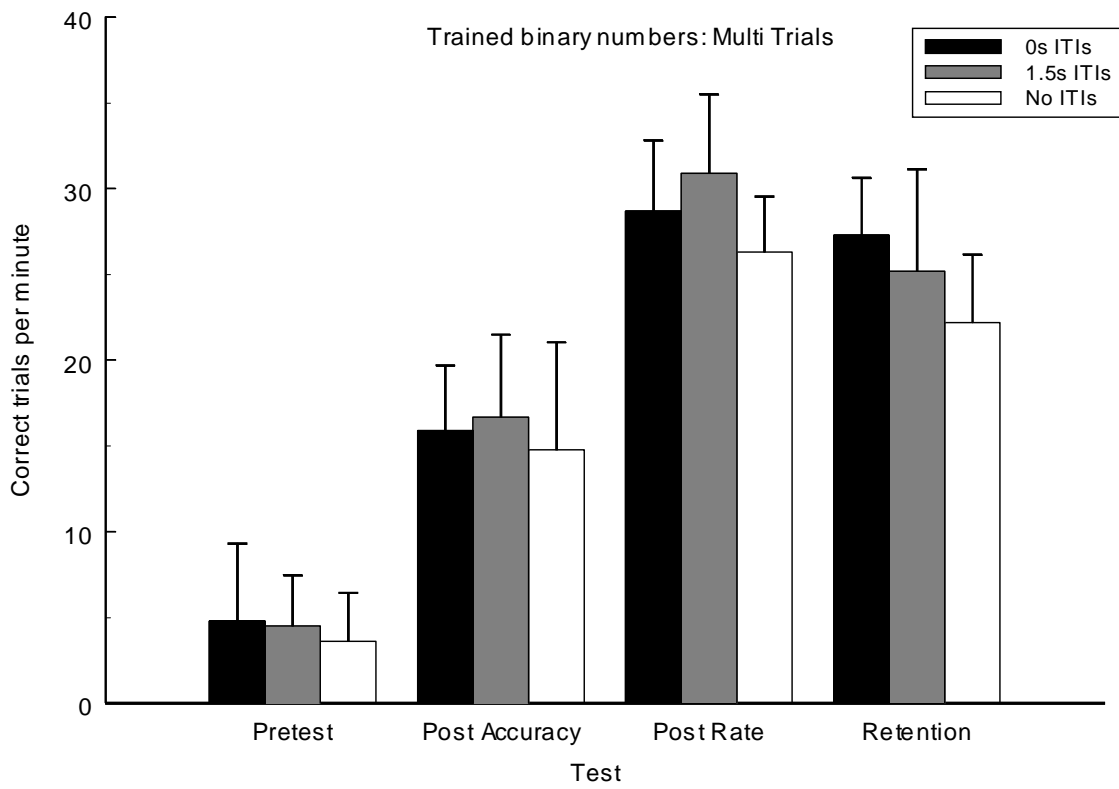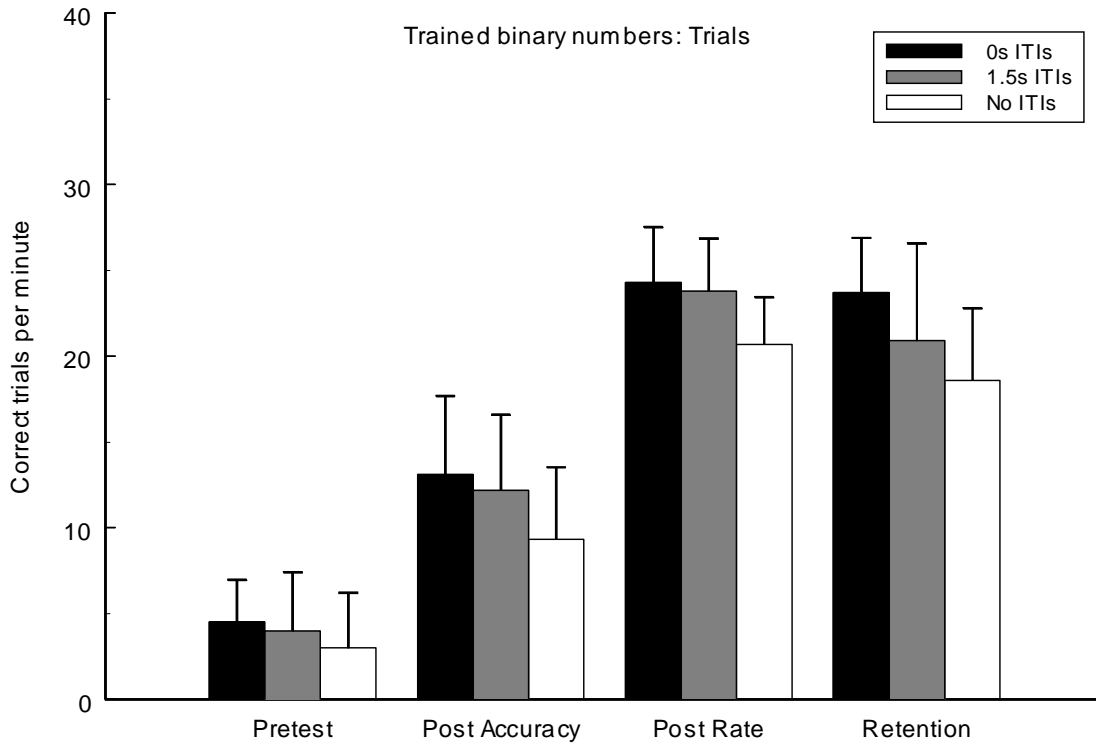
addition, subjects who received 1.5s ITIs training performed better than the No ITIs

subjects on the Post Rate test ($\underline{t}$ (18) = 2.39, $\underline{p}$ = .028). When Multi-trial presentations

were used, 1.5s ITIs subjects responded faster than No ITIs subjects on the Post rate test

($\underline{t}$ (18) = 2.58, $\underline{p}$ = .019), and 0s ITI subjects responded faster then No ITIs on the

Retention test ($\underline{t}$ (18) = 3.13, $\underline{p}$ = .006). No other differences in performance on the four

tests were found between the different training methods.

Paired sample t-tests were used to assess any changes in performance throughout

training. The top panel of figure 3 shows that when subjects were tested using Trial

presentations, all training conditions showed significant increase in number of correct

responses to trained binary numbers after Accuracy training ($\underline{t}$ (9) = -5.16, $\underline{p}$ = .001, $\underline{t}$ (9)

= -5.80, $\underline{p}$ < .001, and $\underline{t}$ (8) = -3.67, $\underline{p}$ = .006 for 0s ITIs, 1.5s ITIs, and No ITIs,

respectively) and a further increase following Rate training ($\underline{t}$ (9) = -6.98, $\underline{p}$ < .001, $\underline{t}$ (9)

= -7.59, $\underline{p}$ < .001, and $\underline{t}$ (8) = -6.13, $\underline{p}$ < .001 for 0s ITIs, 1.5s ITIs, and No ITIs,

respectively). No change in rate of correct responding was found between the Post Rate

test and the Retention test ($\underline{t}$s (9) = .45, 1.58, and 1.41, $\underline{p}$s > .05 for 0s ITIs, 1.5s ITIs, and

No ITIs, respectively). As can be seen in the bottom panel of figure 3, similar results

were found when subjects were tested using Multi-trials. The number of correct

responses increased for subjects in all conditions after Accuracy training ($\underline{t}$s (9) = -7.29

and –10.94, $\underline{p}$s < .001 for 0s ITIs and 1.5s ITIs, respectively, and t (8) = -6.32, $\underline{p}$ < .001

for No ITIs) and also after Rate training ($\underline{t}$s (9) = -7.29, -10.94, and –6.32, $\underline{p}$s < .001 for

0s, 1.5s, and No ITIs, respectively). On the Retention test, however, subjects who had

received 1.5s ITIs and No ITIs training showed a significant decrease in performance, from 30.9 to 25.2 and 26.3 to 22.2 correct responses, respectively ($\underline{t}$s (9) = 3.99 and 3.95, $\underline{p}$s = .003). The 0 ITIs subjects' performance did not decrease significantly ($\underline{t}$ (9) = 1.14, $\underline{p}$ = .285) on the retention test.

Figure 3 also indicates that except on the Pretest subjects from all three training conditions performed faster when trained binary numbers were presented using the Multi-trial approach as opposed to the Trial approach. The means for the Trial and Multi-trial test components on trained binary numbers are shown in Table 5. A paired-sample t-test comparing these two test components at all four tests obtained a $\underline{t}$ (29) = .73, $\underline{p}$ > .05, $\underline{t}$ (29) = 5.02, $\underline{p}$ < .001, $\underline{t}$ (29) = 7,91, $\underline{p}$ < .001, and $\underline{t}$ (29) = 6.13, $\underline{p}$ < .001 for the Pretest, Post Accuracy, Post Rate, and Retention test, respectively.

No differences in latency of responding to trained binary numbers were found between the three training conditions, regardless of presentation mode and test (Pretest through Retention).

The two graphs in figure 4 represent testing on **untrained binary numbers** using Trial and Multi-trial presentation modes. No statistically significant differences were found between any of the three conditions at any of the four tests for either presentation mode. Subjects in all training conditions, however, showed a significant increase in number of correct responses to untrained binary numbers after Accuracy training for both presentation modes (for Trial presentations: $\underline{t}$ (9) = -3.48, $\underline{p}$ = .007, $\underline{t}$ (9) = -3.80, $\underline{p}$ = .004, and $\underline{t}$ (8) = -4.26, $\underline{p}$ = .003 for 0s ITIs, 1.5s ITIs, and No ITIs, respectively, and for

Table 5

Mean Number of Correct Responses to Trained Binary Numbers for Trials and Multi-trial Presentation Modes on All Tests, Collapsed Across Conditions.

Presentation mode	Pretest	Post accuracy	Post rate	Retention
Trial	3.8	11.6	22.9	21.1
Multi-trial	4.3	15.8**	28.6**	27.9**

* $p < .01$

** $p < .001$

 Figure 4. Average number of correct responses (trials) per minute to untrained binary numbers on Pretests, Post Accuracy, Post Rate, and Retention tests for the three training methods. Black bars represent 0s ITIs training, gray bars represent 1.5s ITIs training, and white bars represent No ITIs training. The upper panel shows testing using Trial presentations and the lower shows Multi-trial presentations. The error bars represent standard deviation.

Untrained binary numbers: Trials

Untrained binary numbers: Multi Trials
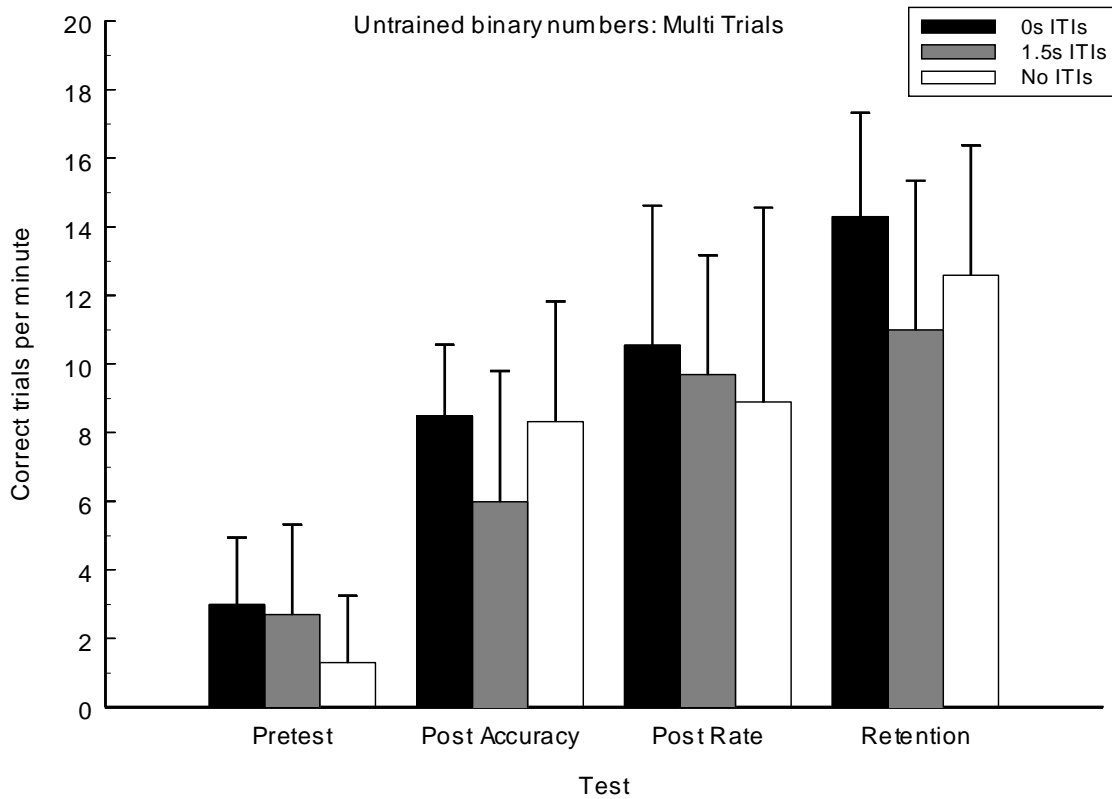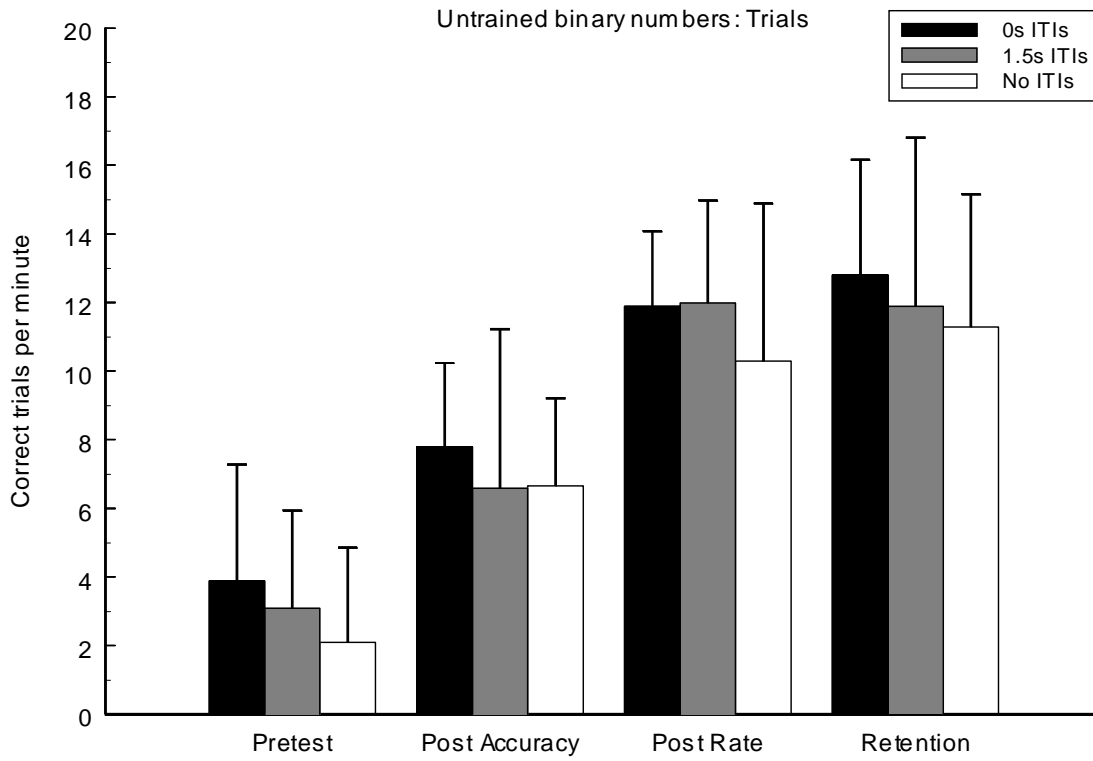
Multi-trials presentations: ($\underline{t}$ (9) = -6.71, $\underline{p}$ < .001, $\underline{t}$ (9) = -3.19, $\underline{p}$ = .011, and $\underline{t}$ (8) = -6.20, $\underline{p}$ < .001 for 0s ITIs, 1.5s ITIs, and No ITIs, respectively). A further increase in rate of correct responding was observed following Rate training for 0s ITIs and 1.5s ITIs, when the Trial presentation mode was used ($\underline{t}$s (9) = -5.07 and -4.75 respectively, $\underline{p}$s = .001), and for 1.5s ITIs when the Multi-trial approach was used ($\underline{t}$ (9) = -3.51, $\underline{p}$ = .007). On the Retention test, performance remained the same as on the Post Rate test for all three conditions when Trial presentations were used, but the 0s ITIs group and the No ITIs group further improved their performance when Multi-trial presentations were used ($\underline{t}$ (8) = -3.02, $\underline{p}$ = .016 and $\underline{t}$ (9) = -4.13, $\underline{p}$ = .003, respectively).

The mean number of correct responses to untrained binary numbers on the Trial and Multi-trial components are shown in Table 6. There were no differences in rate of correct responding between the two presentation modes except on the Post Rate test, where the mean number of correct responses to untrained binary numbers was 11.4 for the Trial presentation mode, and 9.7 on the Multi-trial mode ($\underline{t}$ (28) = 3.0, $\underline{p}$ = .006).

No differences in latency of responding to untrained binary numbers were found between the three training conditions, regardless of presentation mode and test (Pretest through Retention).

Figure 5 shows the number of correct trials per minute on tests of simple **math problems** involving addition and subtraction presented in binary numbers using Trial (top panel) and Multi-trial (bottom panel) presentation modes. No differences were

Table 6

Mean Number of Correct Responses to Untrained Binary Numbers for Trials and Multi-trial Presentation Modes on All Tests, Collapsed Across Conditions.

Presentation mode	Pretest	Post accuracy	Post rate	Retention
Trial	3.0	7.0	11.4	12.0
Multi-trial	2.3	7.6	9.7*	12.6

* $p < .01$

Figure 5. Average number of correct responses (trials) per minute to math problems in

presented in binary numbers on Pretests, Post Accuracy, Post Rate, and Retention tests

for the three training methods. Black bars represent 0s ITIs training, gray bars represent

1.5s ITIs training, and white bars represent No ITIs training. The upper panel shows

testing using Trial presentations and the lower shows Multi-trial presentations. The error

bars represent standard deviation.

Math in binary numbers: Trials

Math in binary numbers: Multi Trials
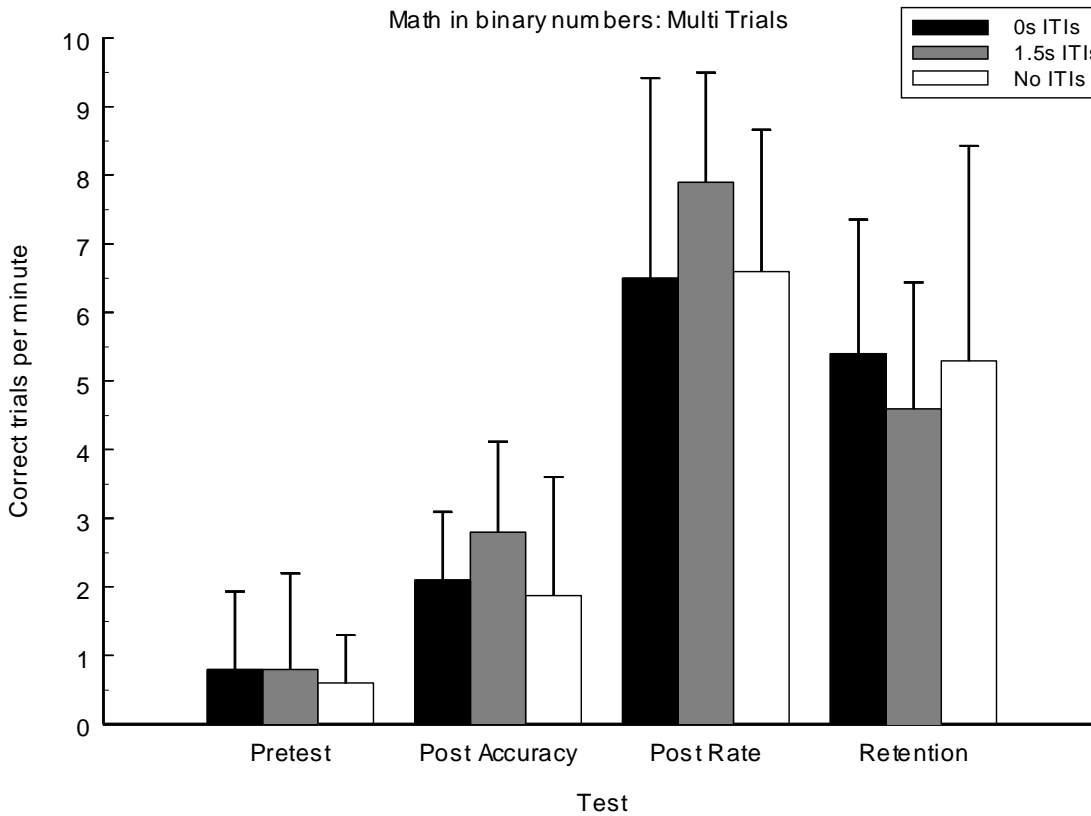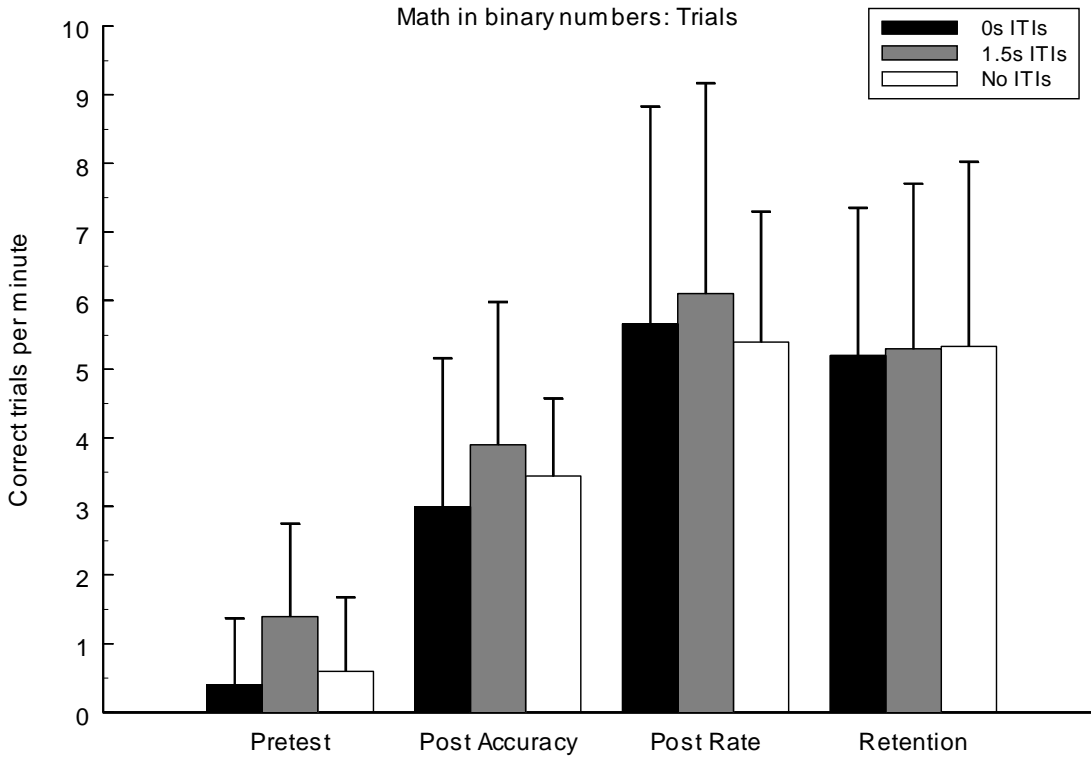
found between any of the three conditions at any of the four tests, regardless of

presentation mode (Trial and Multi-trials).

Subjects in all three conditions, however, showed a significant increase in rate of

correct responding to math problems after Accuracy training when the math problems

were presented using the Trial presentation mode ($\underline{t}$ (9) = -3.55, $\underline{p}$ = .006, $\underline{t}$ (9) = -4.04, $\underline{p}$

= .003, and $\underline{t}$ (9) = -7.62, $\underline{p}$ < .001 for 0s ITIs, 1.5s ITIs, and No ITIs, respectively). A

further increase in performance was observed after the completion of Rate training, for

0s ITIs and No ITIs training ($\underline{t}$ (8) = -4.82, $\underline{p}$ = .001 for 0s ITIs and $\underline{t}$ (8) = -3.79, $\underline{p}$ = .005

for No ITIs) but not for 1.5s ITIs. The performance on the Retention test did not differ

from the Post Rate test for any of the three training methods. When the Multi-trial

presentation mode was used, subjects in the 0s ITIs and 1.5s ITIs groups showed

significant improvement on the Post Accuracy test ($\underline{t}$ (9) = -3.28, $\underline{p}$ = .009 and $\underline{t}$ (9) = -

4.05, $\underline{p}$ = .003, respectively). Subjects in all conditions showed an increase in rate of

responding after Rate training ($\underline{t}$s (9) = -5.56 and -7.39 for 0s ITIs and 1.5s ITIs,

respectively, $\underline{p}$s < .001, and $\underline{t}$ (7) = -9.70, $\underline{p}$ < .001 for No ITIs). There was a significant

drop in rate of correct responding for the 1.5s ITIs group ($\underline{t}$ (9) = 5.21 , $\underline{p}$ = .001) on the

Retention test, but performance did not change during the two week layoff period for the

other two groups, 0s ITIs and No ITIs.

The mean number of correct responses to math problems presented in binary

numbers for both Trial and Multi-trial presentations is shown in Table 7. After

completing Accuracy training, subjects performed faster when the math problems were

Table 7.

Mean Number of Correct Response to Math Problems Presented in Binary Numbers for

Trials and Multi-trial Presentation Modes on All Tests, Collapsed Across Conditions.

Presentation mode	Pretest	Post accuracy	Post rate	Retention
Trial	0.8	3.4	5.7	5.3
Multi-trial	0.7	2.3*	7.1*	5.2

* $p < .01$

presented using the Trial method than the Multi-trial method, or 3.4 and 2.3 correct responses per minute, respectively (t (27) = -3.35, p = .002). However, after Rate training, this pattern was reversed as subjects responded faster when the Multi-trial presentations were used as opposed to Trial presentations, 7.1 versus 5.7 correct response, respectively (t (28) = 2.90, p = .007).

No differences in latency of responding to math problems presented in binary numbers were found between the three training conditions, regardless of presentation mode and test (Pretest through Retention).

A comparison of Figures 3, 4, and 5 shows that response rate, like accuracy, was a function of the type of task being tested. As shown in Tables 8 and 9, subjects generally responded the fastest to trained binary numbers, then at an intermediate rate to untrained numbers, and the slowest to math problems presented in binary numbers. This trend was consistent for all three training conditions regardless of presentation mode. No interaction was found between training method and type of testing task. Therefore, the data were collapsed across conditions and a statistical analysis using repeated measures analysis of variance (ANOVA) and paired sample t-tests conducted to compare the rates of correct responding to the three different tasks at both presentation modes for all tests throughout training (Pretest through Retention test). As shown in Tables 8 and 9, significant main effects at p < .001 were found for type of task on all tests (Pretest, Post accuracy, Post rate, Retention) regardless of presentation mode. The mean rates of responding to the three types of trials at all tests are shown in Tables 8 and 9, along with

Table 8.

The Mean Rate of Correct Responding for All Subjects to Trained and Untrained Binary

Numbers, and Math Problems Presented in Binary on All Tests for Trial Presentations,

Including Degrees of Freedom (Df) and F values for a Repeated Measures Analysis of

Variance of the Three Tasks. The Lower Panel Shows Simple Comparisons Between

Tasks at All Tests where T = Trained Trials, U = Untrained Trials, and M = Math Trials.

	Test			
Type of Task	Pretest	Post Acc.	Post Rate	Retention
Trial presentations:				
Trained	3.8	11.6	22.9	21.0
Untrained	3.0	7.0	11.4	12.0
Math	0.8	3.4	5.7	5.3
Df	(2, 58)	(2, 56)	(2, 56)	(2, 56)
F	21.68*	60.28**	358.06**	222.8**
Simple comparisons:				
	T U	T > U**	T > U**	T > U**
	U > M**	U > M**	U > M**	U > M**
	T > M**	T > M**	T > M**	T > M**

* $p < .05$

** $p < .01$

Table 9.

The Mean Rate of Correct Responding for All Subjects to Trained and Untrained Binary Numbers, and Math Problems Presented in Binary on All Tests for Multi-trial Presentations, Including Degrees of Freedom (Df) and F values for a Repeated Measures Analysis of Variance of the Three Tasks. The Lower Panel Shows Simple Comparisons Between Tasks at All Tests where T = Trained Trials, U = Untrained Trials, and M = Math Trials.

	Test			
Type of Task	Pretest	Post Acc.	Post Rate	Retention
Multi-trial presentations:				
Trained	4.3	15.8	28.7	24.9
Untrained	2.3	7.6	9.7	12.6
Math	0.7	2.3	7.2	5.1
Df	(2, 58)	(2, 54)	(2, 56)	(2, 56)
$\underline{F}$	23.75**	129.22**	331.70**	351.29**
Simple comparisons:				
	T > U**	T > U**	T > U**	T > U**
	U > M**	U > M**	U > M**	U > M**
	T > M**	T > M**	T > M**	T > M**

* $\underline{p} < .05$

** $\underline{p} < .01$

degrees of freedom and F values for the ANOVA. The t-test simple comparisons are also reported in the tables. They showed that all but one comparison was significantlydifferent at $p > .001$. The only non-significant comparison was on the difference between responding to trained and untrained binary numbers when Trial presentations were used.

A repeated measure ANOVA was conducted to test for any interaction between order of testing, training effects, and testing administrations, but none were found.

Discussion

The purpose of this study was to evaluate the effectiveness of three training methods for developing fluency. Fluency was evaluated with respect to retention and performance on application (untrained binary numbers) and adduction tasks (math problems in binary). The main results of the study showed that all training methods produced significant learning and retention, but they differed in a number of subtle ways that may be important. Some of the results support further studies needed for clarification.

Effectiveness of training

All three methods were effective in teaching subjects to translate binary numbers into decimal numbers. Accuracy of responding on trained binary numbers increased significantly between Pretest and Post Accuracy test. Accuracy remained the same throughout rate training and was maintained on a Retention test. Rate of correct

responding also increased after accuracy and rate training for all training methods and was maintained on most tests of retention.

The three training methods were also effective in producing changes in rate and accuracy of translating novel binary numbers into their decimal equivalents and calculating binary addition and subtraction problems. Accuracy and rate of responding increased significantly as a result of accuracy training. Rate of responding to these tasks also increased after rate training. In most cases rate of responding was maintained or increased even further on tests of Retention. These significant changes in performance on these related quantitative skills were achieved in a relatively short period of time. Time spent in training was 61 minute on the average with a rang from 4 minutes to 157 minutes, indicating the effectiveness of repeated practice with a computerized training package.

Efficiency of training

The experiment revealed significant differences between methods that might be of interest. Probably the most important were the differences in the amount of practice and time it took subjects to achieve mastery of translating binary numbers into decimal numbers. Subjects who received No ITIs training only took 29 one-minute timings and about 700 training trials on the average to meet the rate criterion, while it took over twice as many trials, 1423, and time, 60 one-minute timings, for 0s ITIs subjects to reach the same criterion. As the 1.5s ITIs subjects were yoked to 0s ITIs subjects, they underwent the same amount of training, but it took them over 90 one-minute timings to finish.

These differences were significant and indicate that No ITIs training is more efficient than 0s ITIs, which in turn is more efficient than 1.5s ITIs training. These findings are bolstered by differences in response rates to the different methods for presenting the trained binary numbers on tests. Subjects generally responded faster when the Multi-trial method was used than when the Trials methods was used. These differences were significant on all posttests involving trained binary numbers.

These findings suggest that presentation mode affects the rate at which subjects can respond. Subjects respond faster when multiple tasks are presented as opposed to the one task at a time, even when single tasks were presented with fast computer technology. These findings are consistent with speculations that are prevalent in the literature on fluency training and Precision Teaching (Binder, 1988; Binder, 1993; Johnson & Layng, 1996) about the superiority of No ITIs methods over typical discrete trial methods. When presented with multiple trials in a single workspace, subjects may begin to respond to a new problem while still responding to a previous one (K. R. Johnson, personal communication, May, 1997). This idea is supported by research on perceptual span in reading, where subjects appear able to extract useful information from about 15 character positions from a fixation point (Rayner & Pollatsek, 1989). Subjects are, however, prevented from doing this when discrete trial methods such as 0s or 1.5s ITIs are used and subjects' responding is slowed down. Interestingly, presentation mode and increased rate of responding did not seem to affect accuracy of responding, as accuracy was similar for all training conditions regardless of presentation mode and the

rate allowed by that type of presentations. This provides an efficiency justification for the use of training methods, like No ITIs, that facilitate high rates of responding. The more a student can practice within a certain period of time without adversely affecting performance, the better.

Despite procedural differences between 0s and No ITIs, the terminal response rates over the last few one-minute sessions of rate training were almost identical at 29 responses per minute. The rate for 1.5s ITIs was much lower at 17 responses per minute. The latencies of responding, however, were almost identical for all training methods. Therefore, the relatively low rate for 1.5s ITIs training subjects was not a result of longer response latencies, but rather it was due to the imposed 1.5s intervals between trials. Interestingly, this deliberate manipulation of rate did not appear to affect performance on tests either directly after rate training, or on a retention test. This contradicts discussion in the Precision Teaching literature that suggests that higher rates of responding should yield better training outcomes (Lindsley, 1996a, 1996b).

Important differences in test performance

Some differences in test performance, however, were found between subjects in the ITI training conditions and subjects who received No ITIs training. Subjects in both ITI conditions responded faster to trained binary numbers presented in Trials on the Post Rate test than did subjects undergoing No ITIs training. The Os ITIs subjects also responded faster than the No ITIs subjects on a test of Retention when using Trials procedures. Similar differences were found when trained binary numbers were presented

using Multi-trials; 1.5s ITIs subjects outperformed No ITIs on the Post Rate test and 0s ITIs subjects outperformed the No ITIs group on the Retention test. A related difference between the conditions was found on Retention test performance for trained binary numbers presented using Multi-trials. For subjects who received 1.5s ITIs and No ITIs training there was a significant decrease in rate of correct responding on the Retention test from the Post Rate test. No such decrease was observed for subjects in the 0s ITIs training condition. Although these between-condition differences suggest differences between the training conditions, whether the differences are due to characteristics of the training methods or to differing amounts of practice remains unclear. This will be discussed shortly.

Another significant finding was a progressive decrease in rate of responding from trained binary to untrained binary numbers to math problems presented in binary regardless of training condition. Subjects responded to untrained binary numbers at about half the rate they responded to trained binary numbers. When compared to untrained binary numbers, response rate to math problems presented in binary was also halved. A similar trend was observed for accuracy of responding between the three testing tasks. Accuracy was generally lower for math problems presented in binary than for trained and untrained binary numbers. Subjects responded most accurately to trained binary numbers.

These differences indicate two important points. First, these application and adduction tasks are good test tasks for future experimentation because they allow for

improvement that may result from further manipulation of training. Second, these differences evoke questions about the current adequacy of functional definitions of fluency (RESAA). Johnson & Layng (1996) stated that fluency has been achieved when training results in retention, endurance, stability, application and adduction, but they gave no indication of the levels of performance required for each of these outcomes. Retention, endurance, and stability requirements may be fairly straightforward. If the student performs as well on a task after a certain period of no practice or on extended timings and under conditions of distraction, then retention, endurance, and stability have been achieved. A problem arises, however, when testing for application and adduction because these tasks differ from the initial training task.

By definition, application and adduction tasks involve responses in the presence of different stimuli than on the trained tasks. These differences make it difficult to assume that the same rates will apply to these tasks as the trained tasks, which begs the question of how much rates and possibly accuracy on an application or adduction task can deviate from the initial training task to fulfill fluency requirements. Maybe any positive change in rate and accuracy on these types of tasks indicates fluency. This, however, does not seem very pragmatic because it does not distinguish fluent from non-fluent behaviors except in an extreme case of no improvement of application or adduction performance. Binder (1996) briefly addressed this problem by acknowledging the difficulty of the present criteria for fluency. He states that "Simply demonstrating in a systematic fashion that higher performance frequencies improve outcomes in one or

more of the three categories for any behavior class is itself a notable accomplishment…"

(Binder, 1996, p. 174). This indicates that fluency should not be thought of as an all or

none phenomena, but on a continuum, i.e., there are different levels of fluency that

correspond to different levels of behavioral outcomes. Most likely, all training methods

produce fluency to some extent. Some, however, may be more effective than others.

In this study, subjects responded as accurately and as frequently on a test of

retention as they did after training. They also responded correctly to application and

adduction tasks, but their rates and accuracy were lower than on the trained tasks. It is

tempting to conclude that the subjects achieved fluency, but the confusion about what

fluency does and does not entail suggests that conclusions concerning differences and

lack of differences between methods need to be tentative. Lindsley (1996a, 1996b), for

example, suggested that in order to achieve fluency the training rates need to reach at

least 40 responses per minute. This counters the notion conveyed by functional

definitions (Binder, 1996; Johnson & Layng, 1996) and contrasts with Binder's (1996)

suggestion that fluency rates have to be empirically validated for each type of training.

Lindsley's criterion suggests, however, that the rate criterion used for 0s and No ITIs was

not high enough. If a higher criterion had been used, perhaps it would have brought

about more salient differences in the behavioral outcomes of the three training conditions

under investigation.

It also should be acknowledged at this point that the number of statistical

comparisons conducted may have inflated the statistical significance of some of the

comparisons (Type 1 error). In fact, some of the reported differences between the ITI

conditions and the No ITIs condition were actually eliminated when more stringent

comparisons (ANOVA w/Scheffe comparison test) were used. However, considering the

rational for conducting this study, which was a comparison of the three training methods,

the use of t-tests for planned comparisons was justified.

Future questions.

One of the more interesting questions evoked from these data is why the No ITIs

subject performed as well as the 0s and 1.5s ITIs subjects when tested on application and

adduction tasks despite undergoing only half the amount of practice. Repeated findings

suggest that practice makes perfect, i.e., that performance improves monotonically as a

function of the amount of practice (Stevens & Savin, 1962; Bloom, 1986; Carlson,

Sullivan, & Schneider, 1989; Ericsson, Krampe, & Tesch-Romer, 1993; LaBerge &

Samuels, 1974). This predicts that subjects from the two ITIs conditions should do

better than those from the No ITIs condition.

One possible reason for this not happening in the current study is that rate

training using "free-operant" (No ITIs) procedures may produce better learning than the

two ITI techniques under investigation. In other words, the method itself may counteract

the practice effects such that subjects in a No ITIs condition perform as well as the

subjects in discrete trials conditions, who receive more practice. This would be

consistent with claims made that methods used for developing fluent behaviors should

allow the learner to control his own pace (Binder, 1988; Binder, 1993; Johnson & Layng,

1996; Lindsley, 1996). Consistent with this view is the emphasis on rate of responding as the best predictor of performance, not practice.

It is also possible that the design used in this study was not powerful enough to always pick up the differences between the three different training methods. As can be seen in figures 3, 4 and 5, subjects in the No ITIs condition generally responded slower than subjects from the ITI conditions. This is especially salient for trained binary numbers and to some extent for untrained binary numbers and math in binary. Although most of these comparisons were not statistically significant they are consistent with the significant differences found between 0s and No ITIs conditions on Post Rate and Retention tests.

Further, despite differences in practice and rate between training condition, all involved overlearning (Dougherty & Johnston, 1996). All subjects received extensive additional practice after achieving a criterion. Assuming that all subjects had reached optimal levels of performance (asymptote of rate and accuracy) it could be argued that such overlearning made it difficult to distinguish differences between the three training conditions on the basis of their performance on tests.

In addition, it is important to note again that practice was confounded with method of presenting the tasks during rate training in the current experiment. Further research aimed at getting around this confound is needed. For example, it might be appropriate to run two more conditions, one using No ITIs training that is yoked to the amount of practice received by the 0s ITIs subjects, and another using 0s ITIs training

that is yoked to the amount of practice received by the No ITIs subjects. Although these modifications control for practice, it may still be difficult to draw definite conclusions from the results if there are differences in rate between the groups. Based on the results of the present study, the No ITI subjects will be likely to obtain higher rates with the same amount of practice. Thus the practice/method confound will be replaced with a rate/method confound. Untangling rate and method may require more elaborate procedures.

In light of the emphasis on rate of responding to produce fluency, a second interesting question arises from the 1.5s ITIs subjects doing just as well on tests as 0s ITIs and No ITIs subjects, in spite of being trained at half the rate. According to most of the discussions of methods used for achieving fluency, rate is important (Johnson & Layng, 1996). For example, Lindsley (1996a) claims that "true" fluency cannot be reached when rates do not exceed 20 responses per minute. A comparison of the 0s and 1.5 ITIs training methods shows no difference in retention, application, and adduction despite the 0s ITIs subjects achieving a rate of 29 responses per minute and the 1.5s ITIs subjects responding at only 17 responses per minute.

This lack of differences suggest that rate of responding during training is not important. In this case at least, it seems that most effects of rate are shadowed by practice effects, i.e., equal amounts of practice seem to predict equal behavioral outcomes regardless of rate. This is consistent with studies on the effects of practice on learning (Ericsson, Krampe, & Tesch-Romer, 1993). Latencies of responding, however,

were the same for the 0s and 1.5s ITIs training conditions. This is not surprising given

equal amounts of practice for both conditions because practice reduces latencies of

responding (Ericsson, Krampe, & Tesch-Romer, 1993; LaBerge & Samuels, 1974). This

suggests the importance of latencies predicting fluency outcomes, not necessarily rate.

This makes intuitive sense. If time is a critical element of fluent performance then the

time from when a stimulus is presented to when a response begins would seem to be a

critical measure. Other measures of time may be dependent on duration of responses,

ITIs, consequences, and other constraints placed on responding by the environment. In a

sense, the whole discussion of discrete trials and free-operant methods or, as re-framed

here, between experimenter imposed and subject imposed constraints on responding,

might be answered by focusing on latencies. Procedures that decrease latencies increase

the likelihood of achieving the performance outcomes of fluency. This includes rate-

building procedures because most often rates and latencies are negatively correlated.

This also includes methods of presenting stimuli that obtain high rates, like the no ITIs

tested here, which show that decreased latencies can be achieved efficiently.

    Another explanation for the lack of differences between the two ITI conditions

comes from basic research on behavioral momentum. Behavioral momentum or

response strength are terms used to describe persistence of responding under new

conditions or in the face of changed contingencies (Lattal, 1989). It has been suggested

that rate of responding is correlated with response strength, where high rates are less

resistant to change than low rates (Skinner, 1938). This position is consistent with

Precision Teachers's emphasis on rate of responding, where it is predicted that higher rates improve performance on trained tasks in the face of distraction (retention, endurance, and stability) and on related tasks (application and adduction). Some studies, however, have shown that high rates of responding may actually be less resistant to change than low rates and that other variables, such as reinforcement frequency and magnitude, may be responsible for behavioral resistance (Nevin, 1974; Lattal, 1989). Because higher rates of responding in the educational literature typically produce higher rates of reinforcement, it may be that the relatively high frequency of reinforcement produced by high response rates, not the response rates themselves, makes responding resistant to change.

The emphasis put on rate of responding within the Precision Teaching paradigm can be adapted to the rationale about the importance of reinforcement rate. As in basic research, higher rates of responding lead to higher rates of reinforcement than do low rates of responding if responding is reinforced on ratio schedules. Therefore, high rate training using ratio schedules should result in skills that do not decrease over time (e.g., retention) and have an increased chance of maintenance in the face of new contingencies (e.g., application) than skills trained with low rates of responding. If equivalent rates of reinforcement were ensured during training of high and low rates, however, low rate behavior should be more resistant to change than high rate behavior. In the present study, a comparison between the 0s and 1.5s ITIs training conditions provides one assessment of the effects of rate of responding on fluency related outcomes. Virtually no

effects were found, even though the 1.5s ITIs subjects responded at lower rates. At first glance, this is not consistent with behavioral momentum. However, these non-differences can be explained with reference to the relation between reinforcement frequency and magnitude. Although there were no differences in rate of reinforcement between the two training methods, there were differences in reinforcement magnitude. The 0s ITIs subjects normally responded correctly to more trials during each timing, which results in more points being added to their score at the end of each timing, thus the magnitude of reinforcement was higher. Thus, the 1.5s ITIs subjects' responding was strengthened by low rates of responding and the 0s ITIs subjects' responding was strengthened by magnitude of reinforcement such that no differences were found.

Further research can be conducted to ascertain if the principles of behavioral momentum found in basic animal laboratories hold for human subjects in educational research. For example, it is possible to manipulate rate of responding while holding practice, and rate and magnitude of reinforcement constant. If the above principles apply, low rates should predict better training outcomes than higher rates.

As described earlier the design of the study may have precluded finding differences. If a more powerful design had been used, perhaps differences would have been found between the 0s and 1.5s ITIs conditions. The fact that 1.5s ITIs subjects' performance decreased on two occasions between Post Rate and Retention tests may suggest that rate had some effects. The analysis of latencies, however, suggests that this is not a fruitful avenue to pursue. Even if ITIs were increased even further to manipulate

rate, the fact that subjects' latencies were nearly identical suggests that the critical temporal measure of responding is affected by practice, not rate.

A third interesting addition to this study would be to determine the minimum rates at which fluency is achieved, and then parametrically manipulate these rates to see what effects they have on retention and performance on application and adduction tests. According to the literature on Precision Teaching, fluency is evaluated with respect to the behavioral outcomes of specific rates of responding, i.e., retention, endurance, stability, application, and adduction (Johnson & Layng, 1996). As noted earlier, however, a change in application and adduction can be achieved while leaving room for improvement. In addition, some have claimed that there are certain minimum rates of responding that are required for achieving fluency, such as 40 responses per minute (Lindsley, 1996b).

Manipulation of this sort has important implications in education as it suggests grounds for discussing not only the methods used for achieving fluency, but also the skills that should be trained to high rates (Hazlett, Chase, & Munson, 1998). If on one hand fluency can only be achieved through training of extremely high rates, it would confine fluency training to very simple basic skills. Responding on composite tasks frequently takes long periods of time due to the complexity of the response. Therefore, complex composite skills may not lend themselves to rate training. If on the other hand, relatively high rates are not crucial, fluency training may be important for any skill, but some skills will be trained to lower rates than others to produce the behavioral outcomes

associated with fluency. Consequently, educators will not have to decide that some skills should be taught with rate criteria and others should not. Rather, they will have to determine the rate criteria that predict important behavioral outcomes like retention, endurance, stability, application and adduction. This would be a step in the direction of solving the dilemma that has arisen about the appropriateness of rate training on component and composite skills (Hazlett, Chase, & Munson, 1998), as well as the controversy about the use of methods for producing fluency.

<u>Conclusions</u>

A few firm conclusions can be drawn from this study. First, the three training methods under investigation differed in terms of efficiency of training. No ITIs training was the most efficient and 1.5s ITIs training was the least. All methods were effective in teaching translation of binary numbers and produced behavioral outcomes that have been correlated with fluency, i.e., retention, application and adduction. Some differences were found between the ITI conditions and the No ITIs condition. These differences, however, were confounded with differences in practice. Consequently, the study did not provide definite answers as to the differential effectiveness of these two types of training methods. Finally, no differences were found between the 0s ITIs and 1.5s ITIs subjects despite differences in rate. Although this lack of differences might be attributed to the lack of power of the experiment to find differences, similar latencies of responding suggest that both conditions had sufficient practice to achieve fluency outcomes. Further

research is needed to enhance the understanding of those different methods of fluency

training.

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Appendix A - Subject Recruitment Form

<u>Subject Recruitment Sign-up Form</u>

Name of Study: Fluency and Controlled-Operant Training Methods

Participants are needed for an experiment using voice recognition computers to be conducted in the Department of Psychology. Only persons who have completed Math 3 or Math 28 and are not Computer Science majors or minors will be accepted for the experiment. The experiment will be conducted in a laboratory in Oglebay Hall during the 1998 spring semester. Participants have the opportunity to earn approximately $5 per hour of participation, which also includes $6 attendance bonus for coming to all scheduled sessions. It will take approximately 3-6 1-hour sessions to complete the experiment.

Please write your name, phone number and the best time to call below.

Name: Phone: Best time to call:

1. _____   _____   _____

2. _____   _____   _____

3. _____   _____   _____

4. _____   _____   _____

5. _____   _____   _____

6. _____   _____   _____

7. _____   _____   _____

8. _____   _____   _____

9. _____   _____   _____

10. _____   _____   _____

11. _____   _____   _____

Appendix B - Subject Selection Test

Subject Selection Test

Please write your answer in the space provided.

1. The binary number 00101 is equal to the decimal number _____

2. The binary number 00111 is equal to the decimal number _____

3. The binary number 10101 is equal to the decimal number _____

4. The binary number 00100 is equal to the decimal number _____

5. The binary number 01001 is equal to the decimal number _____

6. The binary number 11100 is equal to the decimal number _____

7. The binary number 00110 is equal to the decimal number _____

8. The binary number 11101 is equal to the decimal number _____

9. The binary number 10000 is equal to the decimal number _____

10. The binary number 10001 is equal to the decimal number _____

Appendix C - Informed Consent Form for 0s and 1.5s ITIs training conditions.

Informed Consent Form

Fluency: A Comparison of the Effectiveness of Three Computerized Fluency Training Methods

Introduction: I, _____ have been invited to participate in this research study which has been explained to me by Finnur Oddsson. This research is conducted to fulfill requirements for a Masters degree in Psychology at West Virginia University.

Purpose of the Study: The purpose of this study is to compare the effectiveness of three computerized training methods to teach mathematical skills. The study will compare methods for presenting mathematics problems on a computer screen.

Procedures: During this study I will learn to translate binary numbers into decimal numbers. The training method used involves presenting the numbers, one at a time, on a computer monitor. My task is to translate the numbers into decimal numbers. Throughout the study, my performance will be tested using paper and pencil and computerized tests. It will take me about 6-10 hours to complete my participation in the study. Approximately 30 subjects will participate.

Risks and Discomforts: There are no known or anticipated discomforts involved in serving as subject in this study.

Benefits: I understand that this study may not be of direct benefit to me, but might improve my academic skills. The knowledge gained from it may be of benefit to others. My participation in this study will allow me to receive extra credit for classes in which I am eligible to do so. However, there are other ways for me to earn extra credit for these classes. I understand that I may gain up to $xx for my performance during each experimental session and $xx attendance bonus for not missing any sessions without notifying the experimenter. I understand that if I miss two or more scheduled session, and if I do not call in advance of missing a session, I may be dropped from the experiment and forfeit my bonus. Still, I will receive the earnings that I have accumulated. My earnings will be paid to me when I complete my participation.

Contact Persons: For more information about this study, I can contact Finnur Oddsson, at 293-2001 (ext. 826), or his supervisor, Dr. Philip N. Chase, at 293-2001 (ext. 626). For information regarding my rights as a research subject, I may contact the Executive Secretary of the Institutional Review Board at 293-7073.

Confidentiality: I understand that any information about me obtained as a result of my participation in this study will be kept as confidential as legally possible. I also understand that my research record, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities. In any publications that result from this research neither my name nor any information from which I might be identified will be published without my consent.

Voluntary Participation: Participation in this study is voluntary. I understand that I am free to withdraw my consent to participate in this study at any time. Refusal to participate or withdrawal will involve no penalty or loss of benefits and will not affect my grades or class standing. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand.

Upon signing this form, I will receive a copy.

I willingly consent to participate in this study.

_____   _____   _____
Signature of Subject   Date   Time

_____   _____   _____
Signature of Investigator   Date   Time

Appendix D - Informed Consent Form for the No ITIs training condition.

Informed Consent Form

Condition III.
Fluency: A Comparison of the Effectiveness of Three Computerized Fluency Training Methods

Introduction: I, _____ have been invited to participate in this research study which has been explained to me by Finnur Oddsson. This research is conducted to fulfill requirements for a Masters degree in Psychology at West Virginia University.

Purpose of the Study: The purpose of this study is to compare the effectiveness of three computerized training methods to teach mathematical skills. The study will compare methods for presenting mathematics problems on a computer screen.

Procedures: During this study I will learn to translate binary numbers into decimal numbers. The training method used involves presenting many binary numbers simultaneously on a computer monitor. My task is to translate the numbers into decimal numbers. Throughout the study, my performance will be tested using paper and pencil and computerized tests. It will take me about 6-10 hours to complete my participation in the study. Approximately 30 subjects will participate.

Risks and Discomforts: There are no known or anticipated discomforts involved in serving as subject in this study.

Benefits: I understand that this study may not be of direct benefit to me, but might improve my academic skills. The knowledge gained from it may be of benefit to others. My participation in this study will allow me to receive extra credit for classes in which I am eligible to do so. However, there are other ways for me to earn extra credit for these classes. I understand that I may gain up to $xx for my performance during each experimental session and $xx attendance bonus for not missing any sessions without notifying the experimenter. I understand that if I miss two or more scheduled session, and if I do not call in advance of missing a session, I may be dropped from the experiment and forfeit my bonus. Still, I will receive the earnings that I have accumulated. My earnings will be paid to me when I complete my participation.

Contact Persons: For more information about this study, I can contact Finnur Oddsson, at 293-2001 (ext. 826), or his supervisor, Dr. Philip N. Chase, at 293-2001 (ext. 626). For information regarding my rights as a research subject, I may contact the Executive Secretary of the Institutional Review Board at 293-7073.

Confidentiality: I understand that any information about me obtained as a result of my participation in this study will be kept as confidential as legally possible. I also understand that my research record, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities. In any publications that result from this research neither my name nor any information from which I might be identified will be published without my consent.

Voluntary Participation: Participation in this study is voluntary. I understand that I am free to withdraw my consent to participate in this study at any time. Refusal to participate or withdrawal will involve no penalty or loss of benefits and will not affect my grades or class standing. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand.

Upon signing this form, I will receive a copy.

I willingly consent to participate in this study.

_____   _____   _____
Signature of Subject   Date   Time

_____   _____   _____
Signature of Investigator   Date   Time

Appendix E - Pre-training.

How to convert a binary number to a decimal number

1.

A decimal number has a base of 10 and is written in a form that uses the digits from 0-9 (ten digits). For example 1, 9, 76, 354, 1298, etc. A binary number, however, has a base of 2 and is therefore written in a form that uses only two digits, i.e., 0 and 1. For example 1, 10, 101, 10011, 101001, etc.

Write any two binary numbers that are different from those above:

Binary: _____   _____

Check you answers:
Binary: 1001, 1111 (for example)

2.

To convert a binary number into a decimal number, you have to know the column position of the digits. The column position of each digit is determined from right to left. The first column on the right is column 0, the second is column 1, the third is column 2, etc. In the number "456" for example, the digit "6" is in column zero, "5" is in column one, and "4" is in column 2.

What is the column position of the "0" in the following numbers?

a) 110111 _____   b) 2401 _____   c) 6270 _____   d) 907776

Check you answers:
Ans: a) 3   b) 1   c) 0   d) 4

3.

      Just as the column position in the decimal number system indicates decimal units (for example, ones, tens, hundreds, etc.), the column position in the binary number system indicates binary units. The binary units are powers of 2 similar to how decimal units are powers of 10. For binary numbers, column position zero is 2 to the 0 power, column position one is 2 to the 1st power, column position two is 2 to the 2nd power, etc. For example, $2^0 = 1$, $2^1 = 2$, $2^2 = 4$, $2^3 = 8$.

For binary numbers, what do the following column positions stand for?

a) column position 4: _____   b) column position 5: _____

Check you answers:
Ans: a) 2 to the 4th b) 2 to the 5th The column position indicates the power of 2.

4.

      To translate binary numbers into decimal numbers just multiply each digit of the number by 2 (for binary) and by the power indicated by the column position and add the products. For example the decimal equivalent of the binary number "110" is six. The calculation is the following: $1\text{x}2^2 + 1\text{x}2^1 + 0\text{x}2^0 = 4 + 2 + 0 = 6$. Let's look at a few more examples:

Binary	Calculation	Decimal equivalent
1	$1\text{x}2^0 = 1$	1
11	$1\text{x}2^1 + 1\text{x}2^0 = 2 + 1$	3
101	$1\text{x}2^2 + 0\text{x}2^1 + 1\text{x}2^0 = 4 + 0 + 1$	5

Note, that the digit zero in any column is always zero. This is understandable because zero times any number is always zero. Thus you can automatically calculate any column position with zero; it is always zero. Also, multiplying by one does not change the number because one times any number is always equal to that number. Thus, it is sufficient to identify the column positions that have the digit 1 and multiply the base, 2, by the corresponding power. Therefore the above calculation can be simplified:

Binary	Calculation	Decimal equivalent
1	$2^0 = 1$	1
11	$2^1 + 2^0 = 2 + 1$	3
101	$2^2 + 2^0 = 4 + 1$	5

Now, try some yourself. Calculate the decimal equivalent of the following binary numbers:

Binary	Calculation (if necessary)	Decimal
a) 1001		
b) 1010		

Check you answers:
Ans: a) 9   b) 10

5.

When translating binary numbers to decimal numbers it is useful to memorize what each column stands for if the digit "1" is in it. For example, if the digit "1" is in column position 5 it is equivalent to the decimal number 32.

What is the decimal equivalent of the digit "1" in the following column positions?
Column # 0 =_____   # 1 =_____   # 2 =_____   # 3 =_____   # 4 =

Check you answers:
Ans: 1, 2, 4, 8, 16

Test:

Translate the following binary number into decimal numbers:

Binary	Calculation (if necessary)	Decimal equivalent
a) 0001		
b) 1000		
c) 0100		
d) 10001		
e) 11010		

If you missed any, review the instructions again, and find out where you went wrong.

Ans. a)1, b)8, c)4, d)17, e)26 (Answers will not be given).

Fluency and Controlled-Operant Training Methods

by

Finnur Oddsson

Abstract

The study compared the effectiveness three computerized training methods with respect

to behavioral outcomes correlated with fluency. Subjects were trained to translate binary

numbers into decimal numbers. Responses were made orally with the use of voice

recognition software. One training method presented 50 stimuli on a computer monitor

at a time (No ITIs). The other two methods (0s and 1.5s ITIs) presented stimuli

separately on the monitor using discrete trials. Inter trial intervals were manipulated for

the latter training methods. Results showed that all subjects achieved fluent performance

on the training task. Subjects reached rate criterion faster and with less practice when

No ITIs training was used as opposed to 0s or 1.5s ITIs training. Subjects trained with 0s

and 1.5s ITIs, however, performed better than No ITIs subjects on tests immediately after

rate training and also on tests of retention. Little differences were found between the

training methods when tested on application and adduction tasks. No differences in test

performance were found between the 0s and 1.5s ITIs despite considerable differences in

rate of responding during training.

Fluency and Controlled-Operant Training Methods

THESIS

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