Computerized Training Methods: Effects on Retention and Rate of Responding

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ABSTRACT

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The purpose of this dissertation was to evaluate the difference between two methods for presenting training stimuli, Single- and Multi-trials procedures. The former presents one stimulus in a single workspace and the latter presents many stimuli. Experiment 1 attempted to explain why Multi-trial methods sustain higher rates of responding than Single-trials. The results showed that the primary reason for the high rates of responding to Multi-trials is the presence of multiple stimuli, which allow subjects to read ahead to a consecutive stimulus while responding to a previous one. Experiment 2 evaluated the generality of the findings of previous research that suggested that training with Single-trial procedures leads to better retention of learning than training with Multi-trial procedures. Two groups of subjects were exposed to extensive practice after which they were tested for retention and application of the learned skills. The results showed that Multi-trial subjects took less time to reach the practice criterion, but no differences in retention or application between the two experimental groups. The major implications of the findings are that Multi-trials are a more efficient method for presenting training stimuli than Single-trials as they allow for the same amount of practice to be completed in less time. These implications are complicated by the fact that high rates of responding do not necessarily contribute to the effectiveness of training. In fact, there is evidence that suggests that they may even be detrimental to training effectiveness for some tasks.

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Introduction

In recent years, educators within the field of behavior analysis have theorized about the concept of fluency as a measure of training effectiveness. One of the more important aspects of fluency is the training of educational tasks to high rates (e.g., Johnson & Layng, 1994; Binder, 1996; Lindsley, 1992, 1996a, 1996b). To achieve high rates, behavior analysts have recommended extensive practice, one-minute test-timings, special standardized charts to provide feedback on performance, and particular methods of presenting training and testing materials. The methods of presentation involve arranging tasks so that they do not place restrictions on learners' responding to optimize the rate during training (e.g., Lindsley, 1990). To accomplish this, methods that present a large number of stimuli in a single workspace are recommended, instead of more traditional trial methods where stimuli are presented one at a time (Binder, 1996; Johnson & Layng, 1996).

Speculations and a general absence of data on fluency have spurred a handful of experiments intended to validate the importance of some of the factors considered critical for achieving fluent performances (e.g., Carlin, Wirth, Munson, & Chase, 1996; Ellenwood, Chase, & Oddsson, 1998; Hazlett, 1998; Munson, 1998; Oddsson & Chase, 1999; Wirth & Chase, 1995, 1996). Oddsson and Chase (1999) examined the effects of different computerized training methods on the establishment and retention of translating binary numbers into decimals. Specifically, they compared four methods for presenting binary numbers on a computer screen to which subjects responded with decimal numbers.

In one condition, called Multi-trials, more stimuli were presented on the screen than subjects could respond to within a one-minute timing (50 trials). Subjects responded to the stimuli from left to right, as if reading a book. Each response was made to a highlighted stimulus after which the next stimulus was highlighted to indicate it as a target stimulus. In the second condition, called Single-trials, the binary numbers were presented in discrete trials, one at a time, on the computer screen. As soon as the subjects responded, the next stimulus was presented. The time between responding and the next stimulus appearing was identical to the time between responding and the next stimulus being highlighted in the Multi-trials condition. In both cases the time was controlled by the speed of the computer, which resulted in an immediate presentation of the next stimulus. Subjects in these two conditions practiced until they reached a rate criterion of 30 correct responses per minute (Munson, 1998). A third condition, Delayed-trials, was similar to the second, except instead of having a 0-second delay between trials, a 1.5 second blackout, or inter-trial-interval (ITI), separated each trial from the next. The fourth condition was a replication of the Multi-trials condition, but subjects received additional practice beyond reaching the rate criterion. In the last two conditions, subjects were yoked to subjects in the Single-trials condition for the number of practice trials.

After achieving either a rate or a practice criterion, subjects were tested on the previously trained binary numbers, novel six-digit binary numbers, and on simple math problems (addition and subtraction) presented in binary numbers. For testing, the tasks were both presented as Single-trials and as Multi-trials.

One important finding of this study was that subjects responded faster when the Multi-trial presentations were used than when the same tasks were presented in a Single-trial mode. This finding was observed with both between and within subject comparisons. Subjects in the Multi-trials condition reached a criterion rate of 30 responses per minute in an average of 696 trials whereas subjects who underwent Single-trial training needed twice as much practice, or 1422 trials. Further differences between Single-trial and Multi-trial training were observed when the number of practice trials was controlled. During the last five one-minute timings of training, subjects who received trials training responded at an average rate of 29 responses per minute while those who received Multi-trials presentations averaged 32 responses per minute. Similarly, throughout training, the Single-trial subjects averaged 22 correct responses per minute while the Multi-trial subjects averaged 25 correct responses.

Within-subject comparisons provided further evidence for the difference between Single- and Multi-trial presentations. When subjects were tested on previously trained binary numbers they responded faster when the numbers were presented in the Multi-trial format as opposed to one at a time, or Single-trial format. This difference was first evident after only 60 trials of training that taught all subjects to accurately translate binary numbers. On this test, 32 out of 39 subjects responded faster to Multi-trial than to Single-trials presentations. On a test after extensive rate training, sometimes exceeding 2000 trials, 37 out of 40 subjects responded faster to stimuli presented as Multi-trials than Single-trials, and on a test after a two-week period of no practice 31 out of 40 subjects still responded faster to Multi-trials. These data demonstrate convincingly that Multi-trial presentations allow for higher rates of responding than do Single-trial presentations.

Oddsson and Chase's (1999) study was designed to make the Single- and Multi-trials presentation modes identical with respect to how quickly the computer operated.

Consequently, the observed difference cannot be attributed to equipment limitations, such as a difference in the speed of presenting stimuli on the computer screen after each response.

The differences between methods of presentations identified by Oddsson and Chase may have important implications for the use of training methods, particularly in computer-based training. In order to extend the generality of these findings, however, it is important to uncover the variables responsible for rate differences between Single- and Multi-trial presentations.

Possible Explanations

Reading Ahead. There are a number of possible explanations for the difference between the Single- and Multi-trial methods of presentation found in Oddsson and Chase (1999). For example, when presented with multiple trials in a single workspace, subjects may be able to respond to multiple questions or stimuli in ways that are not being measured. When multiple stimuli are presented the subject may be saying the decimal equivalent of one binary number while covertly responding to (observing) the next one (K. R. Johnson, personal communication, May, 1997). In Oddsson and Chase (1999) this observing response was not measured. The idea that a learner can respond to two or more stimuli at a time is supported by research on perceptual span in reading. According to Rayner and Pollatsek (1989) subjects are able to extract useful information from about 15 character positions from a fixation point. This potentially facilitates rate of responding to stimuli presented in Multi-trials because of the spatial organization of the stimuli on the screen. Discrete trial methods like Single-trials, however, prevent subjects from responding to such stimuli because apart from the target stimulus, no additional stimuli are present on each trial. Therefore, subjects' responding may be slower on Single-trial presentations, because they are unable to observe more than one stimulus at a time as they can do during Multi-trial presentations.

Feedback. Differences between the Single- and Multi-trial procedures could also be attributed to differences in what best could be described as feedback implicit in the Multi-trials. Although feedback was originally conceptualized as a process underlying automatic control systems (Tustin, 1955), the term has since been adopted by a number of psychologists in an attempt to account for learning of various skills (e.g., Chansky, 1960; Gilman, 1969; Koch & Dorfman, 1979; Mason & Redmon, 1992; Travers, Van Wagenen, Haygood, & Cormick, 1964, Smith, 1963). The behavioral functions of feedback are still poorly understood (Peterson, 1982), but sometimes feedback improves or increases rate of performance (e.g., Anderson, Kulhavy, & Andre, 1971; Karlsson, 1986; Krumbholz & Weisman, 1962), and as such it can be argued that it is functionally equivalent to reinforcement.

In Oddsson and Chase (1999) there were important differences in the feedback between the Single- and Multi-trial procedures. All subjects received feedback on accuracy and rate of responding at the end of each one-minute timing. In addition, when subjects' were responding to stimuli presented in Multi-trials they were able to observe their progress, or rate of responding, throughout each one-minute timing, which was very difficult to do when stimuli were presented with the Single-trials procedure. In the Multi-trial procedure, each completed line across the computer screen consisted of five completed tasks. Subjects could, therefore, readily see when they had completed five, ten, fifteen, etc. tasks, simply by counting the number of lines on the screen. The Single-trials subjects, however, had no clear indication of the number of trials completed at, say, thirty seconds into each timing, but had to wait until at the end of the one-minute to obtain feedback on their rate of responding. Hence, another difference between the two training methods was that in one, subjects were able to observe their progress during the timing interval, while in another, subjects had to wait until at the end of every timing to get feedback on their performance (Greg Stikeleather, personal communication, May, 1998).

Studies on the effects of visual feedback have shown that its delay or absence has been correlated with performance decrements on a variety of tasks such as writing (Tamada, 1995), reading of piano notes (Banton, 1995), and other motor skills (Wulf, Shea & Matschiner, 1998). As the Multi-trials presentations provided subjects with immediate visual feedback on the rate of their performance and the Single-trials presentations did not, it is conceivable that this element of feedback may have reinforced the behavior of solving the binary tasks quickly and consequently subjects achieved higher rates during Multi-trials presentations.

In addition, the above speculations are supported by data on non-human fixed-ratio (FR) responding where a specific dimension of some stimulus is designed to remain proportional to the number of responses since the delivery of the last reinforcer. The presence of such a stimulus, often referred to as a counter, has been shown to increase rate of responding on FR schedules (e.g., Ferster & Skinner, 1957). Although the Multi-trials responding is not on a FR schedule, there are similarities between non-human FR schedules with an added counter and subject's Multi-trials presentations. Loosely speaking, both essentially provide a stimulus change that is related to the progress of responding relative to a certain goal, which may result in a similar effect on response rate for the human subjects as for the non-human subjects.

Prompting. Finally, it is possible that stimuli to which subjects have already responded provide supplementary stimulation (prompts) that allow subjects to respond faster to the target stimulus. This idea is consistent with extensive literature on visual priming, both for human (e.g., Cramer, 1969; Hopkins & Atkinson, 1968) and non-human subjects (e.g., Pietrewicz & Kamel, 1979; Vreven & Blough, 1998). Because Single- and Multi-trial presentations provide subjects with identical histories of stimuli to which they have previously responded, it is not immediately obvious why subjects would be able to respond faster to stimuli presented in Multi-trials than Single-trials. A reasonable explanation, however, would be that in Multi-trials the continued presence of these stimuli on the computer monitor would result in faster responding than the mere history of responding to the same stimuli provided in the Single-trials procedure.

A behavior analytic interpretation of priming in this context would conceptualize the stimuli to which a subject has previously responded as prompts, which have been defined as stimuli that already control a response (Anderson & Faust, 1973). In any list of binary numbers there will be some that have strong discriminative relations and some that have less strong relations. For example, a subject responds by saying "twenty" very quickly in the presence of "10100", but says “twenty-one” less quickly to "10101". When the stimuli that have strong discriminative relations are left on the screen they may function as prompts for responses that are not as likely to occur because of their formal similarities. Thus "10101" is responded to as "twenty-one" because the stimulus is formally similar to "10100" and the response is formally similar to "twenty". Being able to observe such prompts, as in the Multi-trial procedure, may therefore speed up responding relative to conditions where the prompts are absent, as in the Single-trial procedure.

Statement of the Problem

To evaluate these possible explanations, Experiment 1 involved an experimental analysis to isolate the variables responsible for the differences in rate of responding sustained by Single- and Multi-trials methods of presentation observed by Oddsson and Chase (1999). The study examined the role of feedback implicit in Multi-trials presentations and the role of context, both in terms of prompting and subjects' responding to more than one stimulus at a time.

The factors hypothesized to affect rate of responding were examined by comparing the rate of responding sustained by Single- and Multi-trials presentations and three new methods of presenting stimuli on a computer screen. The first condition, called Added-trials, is identical to the Multi-trials method, except that instead of multiple binary numbers being presented on the computer monitor at the beginning of a one minute timing, the stimuli were added as the subjects responded. Subjects started each timing by responding to a binary number in the upper left corner of the monitor. The next number appeared on the monitor only after a response had been recorded to a previous number, which remained on the monitor. All numbers to which subjects respond are, therefore, present on the monitor until the end of the timing. This retains the potential feedback and prompting functions of the Multi-trials procedure without allowing responding to two or more stimuli at a time.

The second new condition, called Deleted-trials, is similar to Multi-trials, but instead of leaving the binary numbers on the screen after each response, each number was replaced by five asterisks ("*****") immediately after a response to that number had been recorded. Therefore, the binary numbers visible on the screen at any given time are the number to which the subject is responding and consecutive numbers to which the subject has not responded. This eliminated the effects of prompting while the potential effects of feedback were preserved and the subject could read ahead and observed more than one stimulus at the same time.

In the third new condition, called Seven-trials, seven stimuli are presented on the same line in the middle of the screen. Subjects respond from left to right, as in Multi-trials, but when a response is recorded to the seventh stimulus, the screen is refreshed and seven new stimuli are presented in the place of the previous ones. This condition allowed for some effects of prompting and the subject read ahead and observed more than one stimulus at the same time. The effects of feedback, however, were minimized.

The proposed explanations of differences in rate sustained by Single- and Multi-trials presentations suggest a number of possible results. It is worth pointing out that data from each experimental condition in isolation does not support any of the hypotheses. Rather, different constellations of findings are required to support each of the three hypotheses. For example, if the subjects are reading ahead, then their rate of responding should be higher on Multi-, Seven-, and Deleted-trials than on Single-trials and Added-trials.

Method

Subjects

Five 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 that required them to translate 10 binary numbers into their decimal equivalent (see Appendix B). No subject responded accurately to any of the binary numbers on the subject selection test. Additional requirements for participation included the completion of either College Algebra (Math 3) or Finite Mathematics (Math 28). Also, computer science majors were not allowed to participate. All subjects were asked to participate in the study four to five days a week for one hour each day. They were also asked to read and sign an Informed Consent Form prior to their participation (see Appendix C).

Settings and apparatus

Experimental sessions were conducted in 2.2m by 1.8m room equipped with a table, a chair and the apparatus. The 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 the experimental sessions was 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 and 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 numbers “zero” through “fifty-one”, and “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 approximately 5-10 minutes to complete, and ensured the accuracy of the voice recognition apparatus. In addition, for increased accuracy of voice recognition, 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 exceeded 90%.

Experimental Design

The experimental phases are shown in Table 1. After pre-training and training to at least 85% accuracy of translating binary numbers to decimal numbers, all subjects underwent Multi-trial rate-training until their rate of responding fulfilled rate and stability criteria (described below). Following rate training the effect of four experimental conditions (presentation methods) on subjects response rate was evaluated in a semi-randomized alternating treatments design (Barlow & Hayes, 1979).

Procedures

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. Once you have maximized your rate of translating the binary numbers, you will be tested on your performance. For training and testing you will be presented with binary numbers on the computer screen. Prior to training and testing, you will 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 as accurately and as fast as you can. For each correct translation, that is, each correct response you make, you will get one point. You will accumulate these points throughout the

> experiment. Each point is worth $0.0035 (35% of one cent). Therefore, 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.

Then, subjects read a short paper and pencil program explaining how to translate binary numbers into decimal numbers (see Appendix D). Prior to going through the program the following instructions were read by the experimenter:

> Now you will go through instructions explaining how to translate binary numbers 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 [experimenter shows how to]. At the end of the instructions you will be asked to translate a few binary numbers into decimals. Check your answers with the experimenter when you are done.

The final question of the program required subjects to translate five binary numbers to decimal numbers. If they failed to translate all five correctly, they were asked to read the instruction again and correct the answers that they missed on their previous attempt. No subject failed to correct all errors on their second attempt.

<u>Speech Calibration.</u> 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 speech calibration, the experimenter read:

> Now you will be trained to translate binary numbers accurately into decimal numbers. You will go through 3 blocks of 20 binary numbers, where you will receive feedback on you accuracy after every trial. Read the instructions carefully and let the experimenter know if you have any questions.

The following instructions were then 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 or 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 and feedback was given after each response. If a response was correct, that is, the word spoken matched the decimal equivalent of the binary number on the screen, a 800 Hz tone was sounded, 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 200 Hz tone, and the message, “Incorrect, please try again” was presented on the screen. 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 overall accuracy after each block of trials.

Rate training. All subjects underwent identical Multi-trial rate training until their responding had stabilized with respect to rate and accuracy. Before initiating training, the experimenter read the following instructions:

During this training phase you will translate binary numbers into decimal numbers accurately and fast in one-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 training-session. Otherwise, call the experimenter. Remember, that the faster you go and the more accurate you are, the more you will earn.

Prior to each one-minute timing the following instructions were presented on the computer monitor:

> You will now be presented with 70 BINARY numbers on the computer monitor before you. Your task is to translate them into DECIMAL numbers and SAY the answers as FAST as you can without losing ACCURACY. You will have ONE MINUTE to do so. Each correct answer is worth ONE POINT. 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.

Seventy binary numbers then appeared on the computer screen. Subjects responded to as many of the problems on the computer screen as possible in one minute, making their responses vocally, as during Accuracy training. 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.

When a subject’s rate of responding equaled or exceeded 40 correct responses per minute while maintaining 85% accuracy, they were be presented with the following message on the computer screen: “Well done! Please get the experimenter”. When responding did not fulfill these criteria, subjects were presented with additional feedback on their performance. When rate of responding was below 40, but 85% accuracy was maintained, the message "You need to be faster. Try again." was presented on the screen. Otherwise, the feedback “You need to be faster and more accurate.” was presented. When rate and accuracy criteria had been fulfilled on two separate occasions, rate training was terminated and all subjects underwent testing on five different methods of presenting binary numbers on a computer screen, including the Multi-trial method.

Testing. Testing was conducted at the completion of the final rate-training session. The effects of five different methods for presenting binary numbers on rate of responding were evaluated. To reduce any confound due to warm-up effects, all test-sessions started by having subjects translate binary numbers presented in Multi-trials for one one-minute timing. Following the initial Multi-trial timing, subjects were presented with blocks of three one-minute timings of each of five experimental conditions, Multi-trials, Single-trials, Added-trials, Seven-trials, and Deleted-trials presented in a semi-random order, with the order varied across subjects. The order in which the experimental conditions alternated was randomized with the restriction that the same condition could not be presented on consecutive alternations and that each was presented twice in a span of ten alternations. Testing continued for five one-hour sessions, or until visual inspection of data indicated that experimental control has been reliably demonstrated

(Ulman & Sulzer-Azaroff, 1975), whichever came first. During testing subjects received feedback on their performance after each one-minute timing as during rate training.

Prior to each test-session, the experimenter read the following instructions:

> You will now be tested on what you already know about binary numbers. You will be presented with five different methods of evaluating what you have already learned. Except for the first one-minute timing, each testing method will continue for three one-minute timings, after which a new one will start. The testing methods will alternate back and forth throughout this session. The title before the instructions on the startup-screen will indicate to you when a new method of testing is being used. The different tests will be called: Multi-trials, Single-trials, Added-trials, Deleted-trials, and Seven-trials. The tests will differ in how the binary numbers are presented to you; individually in the center of the screen, on a line across the center of the screen, etc. As during rate training, you will receive feedback about your performance after each timing. Remember that your goal is still to go as fast as you can without loosing accuracy. Remember also, that the faster you go, the more money you will earn. Do you have any questions?

Then testing was initiated.

The Multi-trial method of presentation used during testing was identical to that using for rate training. Prior to each timing subjects were presented with the following instructions on the computer monitor:

Multi-trials

> You will now be presented with a series of BINARY numbers presented on the computer monitor. Your task is to translate the binary numbers into DECIMAL numbers and SAY the answer as FAST as you can without losing ACCURACY. You will have ONE MINUTE to do so. As during previous training, each correct answer is worth ONE POINT. You will receive feedback on your performance at the end of each timing. Remember, that the faster you go, the more money you will earn. Please say the word 'GO' to start.

At the end of the one-minute timing, the start-up screen for the next timing was presented immediately and subjects were instructed to say "GO" to start again. This continued until three timings had been completed, after which the experimenter entered and initiated testing on the next experimental condition.

Except for the absence of immediate feedback after each trial, the Single-trials condition was identical to the method of presenting binary numbers used during Accuracy training. The binary numbers were presented centered on the computer monitor, one at a time, and subjects responded by saying the corresponding decimal number. After each response a 0 s ITI was programmed so that the next stimulus was presented immediately. Prior to each timing, subjects were presented with instructions identical to those used for the Multi-trial tests, except for a different title, "Single-trials". At the end of the one-minute timing, the next one was started immediately as described for the Multi-trials testing. This continued until three timings had been completed.

The Added-trials condition was similar to the Multi-trial method, except that instead of seventy binary numbers being presented on the computer monitor at the beginning of the timing, only one stimulus appeared on the screen and subsequent stimuli were added one at a time as the subjects responded. Prior to each timing subjects were presented with instructions identical to those presented for the Multi-trials condition, except that the test title was replaced with "Added- trials". At the end of the one-minute timing, the next timing started as described previously, until three timings had been completed.

The only difference between the Deleted-trials and the Multi-trials conditions was that in the former the numbers to which subjects had already responded were deleted, or replaced with asterisks. For example, the number "01010" was be replaced with "*****" immediately after a response had been recorded. Prior to each timing subjects received instructions identical to those presented before the Multi-trials condition, with the test title "Deleted trials". At the end of the one-minute timing, the next timing started immediately as described previously, until three timings had been completed.

In the Seven-trials condition seven binary numbers were presented in a horizontal line across the middle of the computer monitor where the target stimulus was always highlighted. When the subject responded to the seventh stimulus, seven new stimuli would appear on the screen with the first one highlighted as a target stimulus. The instructions were identical to those presented prior to Multi-trial timings, except for the test title, which was "Seven-trials". At the end of each one-minute timing, the next one started immediately as described previously, until three timings had been completed.

Payment contingency. Throughout the experiment, subjects earned $0.0035 for each correct response. In addition, subjects earned an attendance bonus of $1 per session. All earnings were paid at the end of subjects' participation.

Results

Pre-training

The five subjects completed the programmed instruction on binary numbers within 25 minutes. No subject made an error during pre-training

Accuracy training

All subjects achieved better than 85% accuracy by their second block of accuracy training trials. Accuracy of responding on the last block of training trials for individual subjects was 100%, 90%, 95%, 95%, and 85% for H61, H63, H64, H66, and H67, respectively.

Rate training

Table 2 shows the performance of each subject during rate training. These data show that the five subjects varied considerably in the number of practice trials and time it took them to complete training. However, their overall rate of responding, rate over the last ten timings, and mean accuracy was fairly uniform.

Testing

After the completion of rate training, testing was initiated in an alternating treatments design. The data analysis focuses exclusively on rate of correct responding as rates of incorrect responding were negligible and there were little differences between subjects. Figure 1 shows rates of correct responding to all five methods of presentation for a representative subject (H67). The upper panel shows rates for each of three one-minute timings of each block of trials (treatment) and the lower panel shows the rate per minute averaged over the three one-minute timings of each 3-minute block. These data indicate that rates of translating binary numbers gradually increased throughout the testing phase and differential rates of responding were observed as a function of methods for presenting the binary numbers on the computer screen. The figure shows that rates of responding between Single- and Added-trials were clearly lower than the rates on Multi-, Deleted-, and Seven-trials. These differences were consistent for all subjects in the experiment (see Appendix E for individual data).

No systematic differences in rate of responding were observed for any subject between binary numbers presented in Single- and Added-trials. A close look at rate of responding to three methods of presentation that allow for higher rates indicated that subjects responded slightly faster on Multi- and Deleted-trials than on Seven-trials. This was supported by an analysis of subjects' average latency to respond to each trial averaged across all one-minute timings of the testing phase. Latencies were measured as the duration between the presentation of a stimulus on the computer screen and the beginning of an utterance in response to that stimulus. Figure 2 shows the average time in milliseconds it took subject H67 to respond to each of the first 37 binary numbers. For the Multi-, Added-, and Deleted-trials this was equivalent to analyzing latencies by the first 37 positions in which the stimuli were presented on the computer monitor. When the Seven-trial procedure was used, however, every eighth stimulus was also the first position in a new line of stimuli, and when Single-trials were used, the screen-position was always the same, in the center of the screen. The figure shows that except on the first trial, the latencies for the Single- and Added-trials were generally longer than those for the Multi-, Deleted-, and Seven-trials, which was consistent with the differences in rate observed between these methods of presentation. Although on most trials there were no differences in latencies between the Multi- and Deleted-trials, and the Seven-trial procedure, the latencies to the 8^{th}, 15^{th}, 22^{nd}, 29^{th} and the 36^{th} trials, the first stimuli in each line of seven stimuli, were considerably longer when presented in Seven-trials. The latencies on these four trial positions were virtually the same for the Single-, Added-, and Seven-trial methods of presentation. This increased latency for a few trials during Seven-trial presentations may account for the apparent, albeit slight, difference in rate of correct responding between Seven-trials and Multi- and Deleted-trials. This pattern of latencies by trial position was consistent for the remaining four subjects in the experiment (see Appendix F for individual data).

It is worth noting that at trial number 35, latencies to Single- and Added-trials seem to be decreasing. This apparent decrement in latencies occurred because at the outset of testing, subjects generally did not respond to more than 30 Single- and Added-trials in each one-minute timing. However, towards the end of testing subjects' rate of responding had increased, allowing them to respond to more trials during each timing. Therefore, the shorter latencies shown to trials 35, 36, and 37 were based only on one-minute timings that took place towards end of the testing phase, during which latencies to respond were relatively short. This also suggests that latencies decreased as a function of practice, which is consistent with the increase in rates that was observed as a function of testing for subject H67 in Figure 1.

In order to further analyze how much reading ahead affected the difference in rate of responding and latencies between Single- and Added-trials, and Multi- and Deleted-trials, the average utterance duration for each subject was analyzed. Because Seven-trials presentations were different from the other four conditions in terms of reading ahead, they were not included in this analysis. The difference in average latencies to the low rate methods of presentation (Single- and Added-trials) and high rate methods (Multi- and Deleted-trial) should not exceed the average utterance duration for the high rate methods, unless subjects are either reading ahead by more than one stimulus, or the computer imposes some constraints on rate of responding when stimuli are presented with low rate methods. As illustrated in the upper half of Figure 3, this is because while emitting a response (utterance duration) to stimuli presented in high-rate methods of presentation, subjects are able to read ahead and observe consecutive stimuli for the duration of their utterance to the previous stimulus. This, in effect, may be reducing the length of the recorded latency, but only by a maximum of the duration of the utterance to the previous stimulus.

The average utterance duration for each of the five subjects is shown in Table 3. There were no systematic differences in the duration of utterances between the five methods of presentation under investigation (F (4, 36) = .62, p > .05, F (4, 36) = .12, p > .05, F (4, 36) = 2.52, p > .05, F (4, 36) = 2.48, p > .05, and F (4, 36) = .72, p > .05, for subjects H61, H63, H64, H66, and H67, respectively). Table 4 shows the average difference in latencies to high and low rates methods of presentation, and the average utterance duration to stimuli presented with high rate methods for all five subjects. Also shown is the discrepancy between the differences in latencies and utterance durations. For all subjects the difference in latencies exceeded utterance duration, and for four out of five subjects, the discrepancy exceeded 100 milliseconds.

There were no systematic differences in utterance duration as a function of trial number (or stimulus position).

Discussion

The results of Experiment 1 suggest that the primary reason for the differences in rate of responding observed between Single- and Multi-trial methods of presentation was that when stimuli are presented according to the latter procedure, subjects are able to read ahead and observe a consecutive stimulus while responding to a previous one. Of the five methods of presentation under investigation all subjects responded at higher rates on Multi-, Seven-, and Deleted-trials, but at lower rates on Single- and Added-trials. For two of the three methods to which high rates of responding were observed, Multi- and Deleted-trials, the stimulus that followed the target stimulus was always present while subjects responded to the target stimulus. Before completing a response to a target stimulus, that is, before completing an utterance that represents a particular decimal number, subjects could look ahead and read the next number. The methods of presentation to which subjects responded at low rates, Single- and Multi-trials, preclude subjects from reading ahead as the stimuli that followed the target stimuli were never presented until after a response had been recorded. On Multi- and Deleted-trials, however, subjects read ahead to a consecutive stimulus while responding to a previous number, which accelerates response rates relative to the Single- and Added-trial procedures.

Although response rates to binary numbers presented with the Seven-trial procedure were consistently higher than when Single- and Added-trials were used, they appeared slightly lower than to Multi- and Deleted-trial presentations. This small difference in rate can be attributed to the fact that every eighth stimulus presented according to the Seven-trial procedure shares the characteristics of Single- and Added-trial presentations in that it is not presented until a response has been recorded to the previous target stimulus. This occurs because the line of seven stimuli in the Seven-trial procedure is not refreshed until subjects respond to the last stimulus in the line. Therefore, subjects cannot respond ahead of the last stimulus in each line, resulting in the increased latencies to the 8^{th}, 15^{th}, 22^{nd}, etc. trials and subsequently slightly reduced rates of responding for Seven-trials relative to Multi- and Deleted-trials.

An analysis of the difference in latencies between the methods that allow for reading ahead and those that do not may suggest the extent to which subjects read ahead. The results show that the average difference in latencies between Single- and Added-trials, and Multi- and Deleted-trials most often exceeded the average utterance duration for Multi- and Deleted-trials, sometimes in excess of 100 milliseconds. If subjects read ahead by one stimulus while responding to the target stimulus, the maximum gain in latency should be roughly equivalent to the average duration of the utterance to the target stimulus. This is illustrated graphically in Figure 3 (upper half). Because the difference in latencies exceeded the average utterance duration, it suggests that the rate differences between methods that allow high rates of responding and those that allow lower rates cannot solely be accounted for by the opportunity to read ahead by only one stimulus.

There are two possible explanations as to why the average duration of an utterance is shorter than the difference between latencies to methods of presentation that allow for low and high rates of responding. First, subjects may be reading ahead by more than one stimulus, resulting in a decrement of latencies that is longer than the average utterance duration to the target stimulus. Second, the data may suggest technical deficiencies in the experimental apparatus in that when subjects have completed a response to the target stimulus it may take the computer a fraction of a second to register and recognize the utterance. As shown in the bottom half of Figure 3, the differences in latencies between procedures that do and do not allow reading ahead should become greater as the computer takes longer time recognize each utterance. This should be expected because when the stimulus that follows the target stimulus is available, subjects are able to “make use of” the computer “downtime” by starting to respond to a stimulus that is readily available on the screen even though the computer has not started recording a latency because it is busy doing something else (i.e., recognizing an utterance). It is worth pointing out, however, that the time it takes the computer to move the cursor between stimuli (e.g., in Multi-trials) and present a new stimulus on the screen (e.g., in Single-trials) is always identical. The difference lies solely in when the computer starts recording the latency and whether some methods of presentation allow subjects to start responding to a stimulus before recording of the latency for that response has started.

There was no indication of the validity of feedback and prompting as proposed explanations of the difference between Single- and Multi-trial presentations. The effects of feedback would have been shown in lower rates of responding on Seven-trials than on Multi-, Deleted-, and Added-trials, because subjects only received feedback on their progress during each timing in the latter three procedures. Although it can be argued that the data show such differences between Seven-trials and Multi- and Deleted-trials, these differences are more appropriately accounted by the longer latency to the every seventh stimulus (as discussed above), but not the fact that the feedback intrinsic to Multi- and

Deleted-trials reinforced faster responding. Additionally, the rates on Added-trials were significantly lower than on Seven-trials. It is worth pointing out, however, that subjects reported a preference for methods that allowed them to track their progress through each timing (e.g., “it is better to know how fast you’re going when you’re trying to beat your best score”).

If prompting had caused the rate differences between Single- and Multi-trials, the manipulation in the current experiment should have yielded higher response rates on Multi- and Added-trials than on Deleted-trials. For the first two methods of presentation, surrounding stimuli should facilitate responding, whereas on Deleted-trials stimuli were erased as soon as they had been responded to, thereby eliminating any contextual prompting. As the rates on the Multi- and Deleted-trials were almost identical, and much higher than on Added-trials, prompting of surrounding stimuli does not account for rate differences between the Multi- and Single-trial procedures.

Overall the results of Experiment 1 were clearly accounted for the differences Oddsson and Chase (1999) observed between rates of responding sustained by the Single- and Multi-trial methods of presentation. Higher rates of responding are correlated with methods of presentation that allow reading ahead and lower rates are associated with methods were subjects cannot read ahead. This interpretation of the data is reinforced by an analysis of latencies to certain trial positions in the Seven-trial procedure, where response latencies were longer to trials that subjects could not have observed before completely responding to a previous trial. This explanation is consistent with research on perceptual span in reading, where subjects appear able to extract “useful information from about 15 character positions from fixation“ (Rayner & Pollatsek, 1989, p. 129). In the current study, stimuli were presented six character positions apart from each other. Therefore, it is conceivable that while fixating on one stimulus subjects could read the next one without changing their gaze. Given the nature of this study it is difficult to ascertain the validity of this interpretation.

It is worth pointing out that the higher rates to Multi-trials relative to Single-trials cannot be accounted for solely on the basis of perceptual span. This is revealed in a comparison of latencies to respond to the first stimulus in each line (or every 8^{th} stimulus) for Multi- and Seven-trials. In the former, the latencies to this stimulus were not noticeably different from latencies to the other stimuli. In the Seven-trials procedures, however, latencies to the first stimulus in each line were reliable longer than the latencies to the other stimuli. Because the first stimulus in each line is more than 15 characters from the previous stimulus, the idea of a perceptual span cannot be used to account for the short response latencies to every 8th stimulus presented in Multi-trials relative to the long latencies to this stimulus in Single-trials. It appears therefore, that not only may subjects be reading ahead through their perceptual span, but apparently they are also able to move their eyes to observe the next stimulus in the same or next line during an utterance to the previous one.

Experiment 2

Introduction

Because Experiment 1 succeeded in providing satisfactory explanation for the differential rates allowed by Single- and Multi-trial procedures, Experiment 2 attempted to answer another question occasioned by Oddsson and Chase's (1999) previous research. Oddsson and Chase's results suggested that subjects' retention of the learned materials was better when trained with Single-trial procedures than when training is conducted with the Multi-trial procedure. This trend was evident both through between and within groups analysis of the data. First, the Single-trial subjects responded faster to binary numbers than the Multi-trial subjects on the retention test. Second, the performance of the subjects who underwent Multi-trial training deteriorated significantly between the completion of training and the retention test, whereas the performance of subjects who had undergone Single-trial training did not change. Both of these results were consistent for both methods used to present the stimuli during testing (Single- and Multi-trials).

Retention of learned materials is of utmost importance to most trainers and teachers. This is clearly reflected in the operational definition of fluency, RESAA, where the "R" represents "Retention" (Johnson & Layng, 1996). It is, therefore, important to further explore the differences in retention observed between the Single and Multi-trial training procedures. As shown in Experiment 1, the differences in rate of responding allowed by these two procedures led to a superior efficiency of Multi-trial training compared to Single-trial. If, however, there is a tradeoff between efficiency and effectiveness or quality of learning, the benefits of Multi-trial training may be negated and the emphasis on using Multi-trials procedures and high rates of responding in fluency training may be misguided.

Oddsson and Chase's (1999) comparison of Single- and Multi-trial training suggested that there is in fact a tradeoff between high rates of responding during training and the effectiveness of training as measured on a test of retention. This experiment may be criticized, however, for subject's low rate of responding during training. The rate criteria for the different conditions were set at 30 correct responses per minute, which is a rate some have claimed too low to ensure fluent behavior (Lindsley, 1992, 1996a, 1996b). The results of the current Experiment 1, where some subjects achieved rates in excess of 50 correct responses per minute, show that Oddsson and Chase's rate criterion of 30 responses was nowhere near the optimum rate at which subjects can respond. Additionally, Experiment 1 showed that rate of responding continued to increase with practice beyond 1400 trials, which was the average practice experienced by Oddsson and Chase's subjects. These observations indicate that perhaps Oddsson and Chase did not allow enough practice or sufficiently high enough rates for a true test of the differences between Single- and Multi-trial procedures. In other words, it may be possible that the differences in retention between Single- and Multi-trial training observed by Oddsson and Chase are due to low rates and little practice. Thus, given more practice and higher rates of behavior, the retention differences may disappear and Multi-trial training may even prove more effective than Single-trial training, as some have suggested (Binder, 1996; Johnson & Layng, 1996).

Experiment 2 attempted to address the above criticism by systematically replicating Oddsson and Chase's (1999) experiment, providing subjects with extensive practice to ensure close to optimal rates of responding during training. The practice criterion was set at 4000 trials, which is roughly the amount of training subjects in Experiment 1 needed for their response rate to approximate asymptote, and triple that of average practice underwent by subjects in Oddsson and Chase's study. Subjects had pre-training, accuracy training, and then the experimental manipulation, which consisted of rate training using either Single- or Multi-trials procedures for presenting the training stimuli. Subjects were tested at the completion of each to those training phases.

Additionally, they were tested again two weeks after the completion of rate training. Each test consisted of two types of tasks, 5-digit binary number and simple math problems presented in binary. Both types of task were tested using three different methods of presenting the stimuli on the screen. The three different methods of presentation were Single-trials, Multi-trials, and Seven-trials. Although subjects were tested four times throughout training, the data analysis focused on the last two tests only, as these two tests indicate the level of retention associated with the two training methods.

Method

Subjects

The same procedure was used for recruiting and selecting subjects as in Experiment 1. Twenty West Virginia University undergraduates, randomly assigned to two experimental conditions (Single- or Multi-trials), served as subjects. No subject responded accurately to any of the binary numbers on the subject selection test.

Settings and Apparatus

Same as in Experiment 1.

Experimental Design

The experimental phases are shown in Table 5. After undergoing Pre-training and Speech Calibration that was identical to that of Experiment 1, subjects were tested on their performance (Pretest) before undergoing Accuracy training. Following Accuracy training subjects were tested again (Post Accuracy), after which Rate training was initiated using either Single- or Multi-trial presentations for the two experimental groups. After reaching a practice criterion of 4000 trials, subjects were tested on two more occasions, first immediately following Rate training (Post Rate) and again 2 weeks later (Retention).

Procedures

Testing. All test versions were equivalent in that the problems required the same computational skills, but were different in terms of the order of binary numbers 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 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 except that the last sentence was replaced with the following: "It is very important that you be as accurate and as fast as you can." The first test (after Pre-training and Speech Calibration) was administered towards the end of the first experimental session. All other tests were given at the beginning of a session, that is, subject would reach a criterion, the session was terminated, and a test administered at the beginning of next session.

Each of the four tests consisted of six different sections. The sections presented one of two tasks, either binary numbers to be translated into decimals or arithmetic problems presented in binary, but answered in decimals. Each section showed the tasks with one of three methods of presentation; Single-trial, Multi-trial, or Seven-trial (as described in Experiment 1). As neither group of subjects was trained using Seven-trials, this method for presenting stimuli was used to provide test data independent of the methods of presentation used during rate training. The order in which the different methods of presentation were used was counterbalanced across subjects.

The first task subjects completed on the test involved translating the five digit binary numbers that were taught in the experiment. Subjects were required to translate the binary numbers into decimal numbers (0-31) in a one-minute timing. When the Single-trial presentation mode was used, subjects received the following instructions before being presented with the test:

> Your task is to translate a series of BINARY NUMBERS into decimals 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. REMEMBER, that the faster you go, the more money you will earn. For example, if you see '00000', you should say 'zero'. Please say the word 'GO' to start".

When Multi-trial presentations were used, the instructions were similar except that the sentence "The numbers will be presented on the screen ONE at a time." was replaced with "SEVENTY 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." When Seven-trials were used the instructions were similar to those used for Multi-trials, except that "SEVENTY numbers will be presented on the screen at a time," was replaced with "A FEW numbers will be presented in the CENTER of the screen."

The second task required subjects 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 Single-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'. REMEMBER, that the faster you go, the more money you will earn. Please say the word 'GO' to start".

Prior to testing using the Multi-trial presentations the subjects read the same instructions, 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." Similarly, when Seven-trial presentations were used, the sentence "problems will be presented on the screen at a time" from the Multi-trial instructions was replaced with "A FEW problems will be presented in the CENTER of the screen."

Subjects were presented with these six testing tasks sequentially and data were collected on rate, accuracy, latency, and duration of responding and confidence of recognition.

Pre-training and speech calibration. The procedures for Pre-training and Speech Calibration were identical to those used for subjects in Experiment 1, except that the general instructions explaining the experiment were as follows:

> During this experiment you will be trained to recognize and translate binary numbers into decimal numbers, both accurately and fast. You will accomplish this by interacting with a computer through a voice recognition system. Periodically you will be tested on your performance. Except for the first part of the experiment, most all training and testing will be conducted on the computer. Before each training or testing phase, you will be instructed about what is expected of you. Some instructions will be read to you and some will be presented on the computer screen. Make sure to read the instruction carefully and ask the experimenter if something is unclear. In general, your task will be to translate binary numbers presented on the computer screen into their decimal equivalents as fast as you can. 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. The more points you have accumulated at the end of the experiment, the more money you have earned. The best way to earn money is to translate the binary numbers both accurately and fast. The more accurate you are and the faster you go, the more money you will earn. In addition to performance based earnings you will earn a bonus of $1 for attending each scheduled session. If you miss a session without first notifying the

> experimenter you will forfeit this bonus and you may be dropped from the study. No extra-credit will be given for this experiment.

Accuracy training. Following completion of the Pretest, subjects underwent Accuracy training as described for Experiment 1.

Rate training: After completing the Post Accuracy test all subjects underwent additional practice using one of two training methods, Single-trial and Multi-trial presentations. Before initiating rate training the following instructions were delivered verbally by the experimenter:

> During this next experimental phase you will be trained to translate binary numbers both accurately and fast. You will be presented with binary numbers in one-minute timings. At the end of each one-minute timing you will receive feedback on your performance. The feedback will tell you to go faster, be more accurate, or both. Try to improve your performance as specified by this feedback. Training will continue until you have fulfilled a predetermined training criterion. In general your goal is to translate the numbers into decimals as fast as you can without sacrificing accuracy. Remember, that the faster you go and the more accurate you are, the more you will earn. Press “F3” and “Enter” to start the next one-minute timing.

Ten subjects were exposed to Single-trial training and ten to Multi-trial training. For the Single-trial group, the following instructions were presented on the screen prior to each one-minute timing:

> You will now be presented with a series of BINARY numbers on the computer monitor before you. The numbers will be presented on the screen ONE at a time. Your task is to translate the binary numbers 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. After each timing you will receive FEEDBACK. NOTE how fast you are going by paying attention to ‘NUMBER CORRECT’. REMEMBER, that the faster you go the more money you will earn. For example, if you see '00000', you should say 'ZERO'. Please say the word 'GO' to start.

The instructions for the Multi-trial group were identical to the above, except that the sentence ”The numbers will be presented on the screen ONE at a time” was replaced with "SEVENTY numbers will be presented on the screen at a time. Proceed from left to right, as if reading a book. The number you are working on will be presented in WHITE”.

The feedback at the end of each timing always asked subjects to “Try again” and “to be faster.” When accuracy of responding was below 85% they were also instructed to “be more accurate.” Rate training proceeded until subjects had completed 4000 practice trials, after which training was terminated and subjects were tested.

<u>Payment contingency</u>. Subjects earned half a cent per each correct response during accuracy training, rate training, and testing. In addition, subjects earned an attendance bonus of $1 per session. All earnings were paid at the end of subjects’ participation.

Results

Pre-training

All subjects completed the programmed instruction on binary numbers within 25 minutes. No subject made an error on the first four frames of the program, but five subjects made errors on the final frame, which involved translating five binary numbers into decimals. Four 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 frame. Three of these subjects were in the Single-trial group, and two in Multi-trial group, including the one that made two errors. Most errors involved mistakes in addition or multiplication, but they were quickly resolved.

Accuracy Training

All twenty subjects achieved 85% accuracy or better by their second block of accuracy training trials and the average accuracy across subjects was 83, 95, and 96 % for the first, second, and third blocks of trials, respectively. There were no differences in performance between the two experimental groups for any of the three accuracy training blocks [t (18) = .89, p > .05, t (18) = .29, p > .05, and t (18) = .59, p > .05 for blocks one, two and three, respectively].

Rate Training

Figure 4 captures the primary similarities and differences between rate training conditions. It shows the change in rate of correct and incorrect responding for one representative subject from each experimental group. Subjects H79 and H88 were selected because their performance corresponded well to their respective group averages. A common characteristic was that the rate of incorrect responses remained fairly stable throughout training whereas the number of correct responses increased considerably. For the subject who received Single-trial training (H79) the rate of correct responding increased gradually for about 80 one-minute timings, after which it leveled off and remained around 30 response per minute. A similar trend can be seen for the Multi-trial subject (H88) in that the rates leveled off after about 80 one-minute timings. Rates of correct responding, however, were much higher than for the Single-trial subject, approximating 50 responses per minute. Figure 4 also shows that it took the Multi-trial subject less time to reach the practice criterion (103 one-minute timings) than the Single-trial subject (149 timings).

The above similarities and differences are also reflected in the averages for both experimental groups that are presented in Table 6. Subjects who received Single-trial training spent more time in rate training than subjects who were trained using Multi-trial presentations. Single-trial subjects needed on average 148 one-minute timings to reach the practice criterion of 4000 trials versus 116 one-minute timings for the Multi-trial subjects (t (18) = 4.74, $p < .01$). The accuracy of responding during rate training was above 90% for both groups and no reliable differences were found between the groups in terms of number of correct (t (18) = 1.25, $p > .05$) and incorrect trials (t (18) = 1.25, $p > .05$). Analyses of responding per one-minute timing during rate training showed that the Single-trials subjects made fewer correct responses per one-minute timing than subjects undergoing Multi-trial training, an average of 25 versus 33 (t (18) = 5.30 , $p < .01$), but the rate of incorrect responding was the same for both experimental groups. Similarly, over the last ten one-minute timings, the average rate of correct responding was significantly lower for subjects who underwent Single-trial training than for the Multi-trial subjects, 28 versus 40 responses per minute, respectively (t (18) = 7.15, $p < .01$).

Consistent with differences in rate of responding between the two experimental groups, the Single-trial subjects had longer latencies to respond than the Multi-trial subjects, 1445 versus 997 milliseconds, respectively ($\underline{t}$ (18) = 4.01, $\underline{p} < .01$).

Testing

Subjects in both experimental training groups, Single- and Multi-trial, underwent four tests, Pretest, Post Accuracy, Post Rate, and Retention. Because previous research has shown conclusively that subject performance changes as a function of Accuracy and Rate training (Oddsson & Chase, 1999) and because the experimental question was not concerned with such changes, the Pretest and the Post Accuracy tests were not included in the statistical analysis. The experimental question focused primarily on the effect the two training methods had on retention of accuracy and rate of correct responding. Consequently, only the Post Rate and Retention tests were included in the analysis of variance. For each test, subjects' rate of responding was evaluated on two tasks, binary and math, that were presented using three different methods of presentation, Single-, Multi-, and Seven-trials. Therefore, the design of the experiment was a 2 TRAINING X (2 TESTS X (3 PRESENTATIONS X 2 TASKS)), where the first variable was a between-subjects measure and the remaining three were within-subjects measures. As rates of incorrect responding were negligible and reflected in a measure of accuracy, they were not included in the analysis.

Accuracy of responding. A factorial analysis of variance of accuracy of responding showed no systematic differences between the two training conditions ($\underline{F}$ (1, 17) = .56, $\underline{p} > .05$). In addition, no reliable effects of the order in which the three different presentation methods (Single-, Multi-, and Seven-trials) were presented during testing ($\underline{F}$

(2, 16) = 3.29, $p > .05$) were found. The analysis, however, revealed a significant 3-way interaction between method of presentation, type of task, and test administration (F (2, 34) = 4.47, $p < .05$) (for source tables, see Appendix G). The interaction is presented graphically in Figure 5. The 3-way interaction suggests that the change in accuracy between the three different methods of presentations on the Post Rate and Retention tests is different for binary number than for math problems. The two-way interactions between method of presentation and type of test for binary numbers (Figure 5, upper panel) and for math problems (Figure 5, bottom panel), however, were not statistically significant (F (2, 36) = 3.02, $p > .05$ and F (2, 36) = 2.54, $p > .05$, respectively). The three way interaction is clarified by simple comparisons that show that when binary numbers are presented in Single-trials, subjects responded more accurately on the Retention tests than on the Post Rate test (t (19) = 2.96, $p < .05$), while the accuracy of responding was the same on both tests for Multi- and Seven-trials. Similarly, the accuracy of responding to math problems presented in Seven-trials increased between the Post Rate and Retention tests (t (19) = 2.14, $p < .05$), while it did not change when the problems were presented as Single- and Multi-trials. Thus, a different pattern of results occurred with binary number tasks than with math problems.

A comparison of the top and the bottom panels of Figure 5 shows that subjects always responded more accurately to binary numbers than to math problems presented in binary, regardless of method of presentation and type of test (Post Rate: t (19) = 2.65, $p < .05$, t (19) = 3.45, $p < .01$, and t (19) = 4.90, $p < .01$ for Single-, Multi-, and Seven-trials, respectively. Retention: t (19) = 3.66, $p < .01$, t (19) = 4.03, $p < .01$, t (19) = 2.21, $p < .05$, for Single-, Multi-, and Seven-trials, respectively).

Overall, the data suggest that subjects respond with better accuracy to previously trained binary numbers than they do to math problems in binary. In addition, the period of no practice between the Post Rate and the Retention tests had no adverse effects on retention of accuracy and in fact performance improved for binary numbers presented with Single-trials and for math problems presented with Seven-trials.

Rate of correct responding. A factorial analysis of variance of rate of correct responding revealed no systematic differences between the two training conditions (F (1, 17) = .04, p > .05), indicating that Single- and Multi-trial training did not yield differential performance, either immediately after training (Post Rate) nor after a period of no practice (Retention). Two significant interactions were observed, one between method of presentation and type of task (F (2, 34) = 41.73, p < .01) and the other between method of presentation and test (F (2, 34) = 3.44, p < .05) (for source tables, see Appendix H). The order in which the three methods for presenting stimuli during testing did not systematically affect rate of responding.

Figure 6 illustrates the interaction between method of presentation and type of task. The rates of responding shown in the figure are the average rates collapsed across the Post Rate and Retention tests. The data suggest that there were differences between rates of correct responding for binary numbers and math problems for all three methods of presentation (t (19) = 28.29, p < .01, t (19) = 29.17, p < .01, t (18) = 23.8, p < .01, for Single-, Multi-, and Seven-trials, respectively). The differences in rate between binary numbers and math problems, however, were different depending on type of presentation. Simple comparisons show that the rate at which subjects responded to binary numbers was lower on Single-trial presentations than on Multi- and Seven-trial presentations (t

(19) = 7.76, $p < .01$, t (18) = 8.5, $p < .01$, respectively), but the rates on Multi- and Seven-trial presentations were not different (t (18) = .79, $p > .05$). Rates of responding to math problems were higher on Seven-trial presentations than on Multi- and Single-trials (t (19) = 2.67, $p < .05$, t (19) = 3.23, $p < .01$, respectively), but no differences were observed between the latter two (t (19) = .77, $p > .05$).

Figure 7 shows the interaction between method of presentation and the two test administrations (Post Rate and Retention). The rates of responding shown in this figure are the average rates collapsed across binary numbers and math problems presented in binary. The interaction suggests that there were differences in the average rate of correct responding between Single-trials, and Multi- and Seven-trials on both the Post Rate and the Retention test (Post Rate: t (19) = 6.49, $p < .01$, t (19) = 6.12, $p < .01$, for Multi- and Seven-trials respectively. Retention: t (19) = 5.13, $p < .01$, t (19) = 6.01, $p < .01$, for Multi- and Seven-trials respectively). There was, however, a significant decrement in rates between the two tests only on Multi-trial presentation (t (19) = 4.1, $p < .01$), but not on Single- and Seven-trial presentations (t (19) = 1.17, $p > .05$, t (19) = 1.02, $p > .05$, respectively). These data suggest that rates of correct responding are generally not affected by the period of no practice between the Post Rate and Retention tests, except when they are tested using the Multi-trial procedure for presenting stimuli.

Discussion

The purpose of Experiment 2 was to examine the generality of previous findings that suggested that training with Single-trial procedures for presenting stimuli yields better retention of learning than training with Multi-trial methods (Oddsson and Chase, 1999). More specifically, the study examined the difference between the Single- and

Multi-trial procedures under conditions of more training than was provided for subjects in Oddsson and Chase's study. The quality of learning yielded by the two methods of presentation was evaluated with respect to application of the learned skills (math problems in binary) and retention of rates and accuracy of responding. The results of Experiment 2 showed that the two types of training did not yield any systematic difference in quality of learning. The two training conditions, however, differed with respect to efficiency of training, which may have practical implications for their educational use. Additionally, the methods used for presenting stimuli during testing differed with respect to their sensitivity to changes in performance across time, where Multi-trials seemed to be more affected by a period of no practice than the Single- and Seven-trial procedures.

The following discussion will focus on the implications of the findings of the current study on the differences and similarities of Single- and Multi-trial training methods. In addition, the study will be compared to results obtained in a study by Oddsson and Chase (1999) in an attempt to account for apparently discrepant findings of the two studies.

Efficiency

As previous research using the same procedures (Oddsson & Chase, 1999) or similar procedures (Munson, 1998) has shown, the pre-training and accuracy training were efficient in establishing repertoires of accurately translating binary numbers to decimal numbers. Subjects quickly achieved accurate responding, which suggests that the programmed instruction used for pre-training is an appropriate method for teaching binary numbers.

Both rate-training procedures, Single- and Multi-trials, brought about considerable increases in rate of correct responding in a relatively short period of time. The rapid increase in rates of responding was reduced and seemed to approximate an asymptote when subjects had gone through roughly three quarters of the training trials. There were, however, critical differences between the two training procedures in the time it took subjects to reach the practice criterion and the rate of responding allowed by the two procedures. Subjects who underwent Multi-trial training needed an average of 116 one-minute timings to complete 4000 trials while it took the Single-trial subjects an average of 148 timings, a difference of roughly 30 minutes. This disparity in time to complete training can be attributed to the differences in rate of responding observed during rate training between the two training procedures, where the Multi-trial subjects consistently responded faster than the Single-trial subjects. These rate differences were particularly pronounced towards the end of training when Multi-trial subjects made an average of 40 correct responses per minute to 28 responses for the Single-trial subjects. From the standpoint of education and training, these results may be important because they suggest that Multi-trial methods for presenting training stimuli allow the student to complete the same number of practice trials in a shorter period of time than that required with Single-trial methods.

The results of Experiment 2 are consistent with those obtained by Oddsson and Chase (1999) as well as the findings of Experiment 1 of the current study, where subjects' responding to Multi-trials was always higher than to Single-trials. The results also support anecdotal evidence from the proponents of rate-building, who suggest that one of the advantages that Multi-trial procedures have over discrete-trial procedures, like

Single-trials, are the high rates at which subjects can respond (Binder, 1988; Binder, 1993; Johnson & Layng, 1996).

Effectiveness

As the implications of differences in the efficiency of training (how fast something is taught) can not be discussed meaningfully without a reference to the effectiveness of training (how well something is learned), it is important to examine the effects the different training procedures had on the quality of learning. In this study, performance on tests administered at the completion of training (Post Rate) and again two weeks later (Retention) was used as an indicator of how effective the Single- and Multi-trial procedures were in teaching subjects to translate binary numbers into decimal numbers. The application of the learned skills was also evaluated by having subjects solve simple arithmetic problems presented in binary, both on the Post Rate test and the Retention test.

An analysis of accuracy of subjects' responding (i.e., a ratio of incorrect to correct responses) showed that there were no differences between the two experimental groups. Furthermore, the analysis of accuracy of responding to binary numbers and math problems showed that there was no decrement in performance over a two-week period of no practice. Conversely, there was some evidence for an improved accuracy over the retention period, where subjects' accuracy of responding to binary numbers presented as Single-trials and math problems presented as Seven-trials increased between the Post Rate and Retention tests.

The analysis similarly revealed no differences in rate of correct responding between the group trained with Multi-trials and the group trained with Single-trials.

Interestingly, the three methods for presenting stimuli during testing were differentially sensitive to changes in performance between the Post Rate and Retention tests. Although there was a decreasing trend in rate of correct responding between the Post Rate and Retention tests, a statistically significant decrement was not observed over the retention period when the test stimuli were presented in Single- or Seven-trials. There was, however, a significant decrement in rate of correct responding between the Post Rate and Retention tests when stimuli were presented in Multi-trials.

Rate training was generally effective not only in teaching binary numbers, but also in allowing subjects to solve math problems. There were considerable differences in accuracy and rate of correct responding to binary numbers and math problems presented in binary, in that subjects were faster and more accurate when responding to the former. There were, however, no differences in performance on application tests as a function of method of presentation used for training.

There are a few possible explanations for the results of Experiment 2. First, repeated findings suggest 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 when subjects go through equal number of practice trials, as they did in the two training conditions of Experiment 2, they should do equally well on tests of their learning.

This practice effect may be the most parsimonious account of Experiment 2, but it does not explain the differences in retention found in Oddsson and Chase (1999). In that previous study, Single-trial training yielded better learning than Multi-trial training even though practice was kept constant. A possible account of the discrepant findings might be that only when practice has produced optimum, ceiling, or asymptotic rates of responding, as in Experiment 2, that differences between the Single- and Multi-trial groups disappear. Subjects in both studies underwent extensive training that can be characterized as overlearning (Dougherty & Johnston, 1996), with a practice criterion in Experiment 2 that was almost triple the one used by Oddsson and Chase. Therefore, it can be argued that rates of responding in the experiment 2 were closer to optimal levels than rates of responding in Oddsson and Chase, which may have precluded finding difference between the two experimental groups of the current experiment.

Another reason for the different findings of Experiment 2 and Oddsson and Chase (1999) has to do with the sensitivity of tests of retention. In both studies the retention interval was two weeks of no practice, after which subjects in Oddsson and Chase performed differentially depending on which method of presentation was used during rate training. It is reasonable to assume that because of the extended practice subjects in Experiment 2 underwent, their performance would be maintained for longer periods of time than that of the subjects in Oddsson and Chase. Therefore, it is conceivable that the retention period use in Experiment 2 was not long enough to differentiate between the two experimental groups. Had a longer retention period been used (e.g., 4 weeks instead of 2), differential performance between the experimental groups, similar to that of Oddsson and Chase, might have been observed.

Overall, the results of Experiment 2 suggest that the two training methods did not differentially affect the quality of learning and the ability to apply the learned skills. Regardless of the form of practice, Single- or Multi-trials, rapid learning of the skills being trained was obtained. These findings are a testimony to the effects of practice as a primary determinant of quality of learning. The results of Experiment 2 also suggest that Multi-trial methods are more efficient that Single-trial methods, as the Multi-trials allow for the same amount of practice to be completed in less time. This finding, however, is only important if the different methods for presenting stimuli do not yield different training outcomes with respect to quality of learning. In this context it is worth keeping in mind that Oddsson and Chase (1999 found difference in quality of learning depending on the form of practice. Consequently, there may exist conditions under which certain method for presenting practice trials are more effective than others, which may negate any efficiency advantages Multi-trial procedures have over Single-trial procedures. Further research is needed to validate such speculations.

General Discussion

The purpose of this study was to address two different questions spurred by Oddsson and Chase (1999). Experiment 1 attempted to clarify the reasons for differences in response rates between Single- and Multi-trial methods of presentation. The current results suggest that the primary cause of the higher response rates is that in the presence of multiple stimuli subjects may read ahead and increase their rates. Experiment 2 was intended to cast light on differences between Single- and Multi-trial training procedures with respect to retention suggested by previous research. The data showed that under conditions of extensive practice, differences in retention were eliminated. The results of Experiment 1 and 2 may have various educational implications, some of which will be discussed below.

Implications for Training

As the two experiments in this study and Oddsson and Chase's (1999) study are ultimately spurred by research and theoretical discussion on education, it is important to discuss the possible implications of the findings in an educational context. Before entering into such a discussion, however, it is important to note that further research is required to clarify the validity of some to the proposed explanations (see above) of the findings of both studies. Therefore, some of the conclusions drawn are necessarily tentative.

If there are, in fact, no differences in quality of learning as a function of the training methods tested here, educators should strive to use methods, such as Multi-trials, because they allow for more efficient training than discrete-trials methods like Single-trials. Conceivably, the more a student can practice within a certain period of time without high rates of responding adversely affecting performance, the better. If, however, there are differences in the quality of learning produced by methods for presenting training stimuli, similar to those suggested by Oddsson and Chase (1999), and if these differences persist except at exceptionally high levels of practice, the appropriateness of Multi-trial methods in education may be questioned. Under circumstances where the amount of practice required to reach optimum rates is either unknown or impractical, Single-trial methods, which promote slower rates of responding, might be preferred to Multi-trials methods of presentation. Given that most often teachers do not have information on optimal rates, the ultimate goal of education, retention, might be better served through the use of Single-trial procedures than Multi-trial procedures. Ultimately, a final answer as to the appropriateness of the two methods under investigation will have to await further research to establish either of the two proposed explanations.

It is worth pointing out that the efficiency of Multi-trial procedures also seems to vary as a function of the skills being trained. The results of the current study show that even though rates of correct responding to binary numbers are significantly affected by the method used for presenting stimuli, no differences in rate of responding to math problems were found between Single- and Multi-trial presentations. As the results of Experiment 1 show, the main reason for high response rates to Multi-trial presentations is that the subjects are reading ahead. With the complexity of the math problems, which require translating two binary numbers into a decimal and then performing a simple addition or subtraction, subjects are unable to respond to two problems at a time in the same way they do to simple binary numbers. This lack of difference in response rates can be partially attributed to the actual size of each stimulus. As pointed out earlier, one of the reasons subjects are able to read ahead is that people's perceptual field extends about 15 character positions from fixation point (Rayner & Pollatsek, 1989). Because the math problems and the spaces between them exceeded 15 characters, it should interfere with subjects' reading ahead, reducing the difference between the Multi- and Seven-trials, and Single-trial presentations. As most complex textual stimuli also exceed the size of 15 characters, it can be expected that these results apply to other complex problems as well.

The above suggests that the potential efficiency advantages of the Multi-trial procedures are relevant only when the training tasks are relatively simple and as such allow for reading ahead to consecutive stimuli. This, of course, limits the advantages of

Multi-trials, because except for the training of basic skills, most training focuses on skills that are considerably more complex than responding to binary numbers. Additionally, the fact that Multi-trials do not allow for relatively high rates when used to present complex problems discredits the rate-advantage argument (see below) that is often used in favor of Multi-trials. Consequently, in the context of training of complex stimuli, the use of Multi-trial methods and other methods that allow for reading ahead has no obvious benefits.

Rate of Responding

Previous findings, as well as those of the current study, show that Multi-trial procedures for presenting training stimuli allow for considerably higher rates of responding than do Single-trials. The study also shows that the latencies to respond to stimuli presented as Multi-trials are shorter than the latencies for Single-trials, resulting in superior rates. Previous research has demonstrated that because latencies are a direct function of practice (e.g., Peterson, 1965; Carlin, Worth, & Chase, 1998) an effective way to reduce latencies is to increase practice. Nevertheless, the difference between the latencies on Single- and Multi-trials cannot be attributed to practice effects because practice was controlled for (Experiment 1, within subjects control for practice). Therefore, it appears as if the manipulation of methods of presentation can affect latencies (and rates) in the absence of manipulation of practice. A closer look at the pattern of responding to Single- and Multi-trials (in Experiment 1), however, shows that the reduction in latencies in Multi-trials methods only gives the illusion of shorter latencies. This is because a part of each latency to respond to a stimulus presented as Multi-trial is masked because the subject is responding to the previous stimulus while reading the one for which the latency is measured. This overlap results in a measure of latency that appears shorter than it really is. It can, therefore, be argued that the experiments did not find differences in actual latencies to respond to each stimuli presented in Single- and Multi-trials. The only difference is that in Multi-trials, the latencies overlap with a response to a previous stimulus, resulting in higher rates of responding.

Regardless of the apparent and actual latencies to respond, the fact remains that when responding to simple stimuli, Multi-trials allow for higher rates than Single-trials. This brings up the validity of claims that suggest training under conditions that allow for high rates (Multi-trials), in the absence of difference in amount of practice and reinforcement, has positive effects on learning outcomes (Binder, 1988, 1993; Johnson & Layng, 1996; Lindsley, 1992, 1996a, 1996b). In other words, it has been suggested, that given equal practice with Multi- and Single-trial procedures, the former will yield better retention, endurance, stability, and application of learned skills. Although a number of researchers have emphasized rate of responding as a determinant of quality of learning (e.g., Binder, Haughton, & Van Eyk, 1990; Johnson & Layng, 1996; Lindsley, 1990, 1992, 1996a, 1996b), to date, there exists no convincing empirical evidence to support this notion.

A number of studies have manipulated rate of responding through explicit instruction, contingencies of reinforcement, and methods for presenting stimuli, to evaluate the effects of rate on quality of learning while controlling for the influence of practice. These studies have used a variety of training tasks ranging from the translation of binary numbers to decimals (Oddsson & Chase, 1999), identification of arbitrary relations between stimuli (Wirth & Chase, 1995, 1996), and spelling (Ross, 2000). None of these found an advantage of training at high rates relative to low rate training, with respect to performance on tests of retention and application, and performance under distracting conditions.

Some evidence even suggests that high rates may even be detrimental to learning. Oddsson and Chase (1999) found that although Multi-trials training yielded high rates of responding, subjects performed worse on tests of retention than did subjects who had undergone training with Single-trials, which yield low rates of responding. It is important to point out, that in Oddsson and Chase's study training was terminated before subjects' rates of responding had reached asymptotic levels of rate of responding. The subjects' retention and application performance, however, indicated that they had learned to translate binary numbers into decimals. Therefore, the training necessary to reach asymptotic rates of responding and to eliminate differences in retention between Single- and Multi-trials training could be viewed as a negative effect of the Multi-trial procedure and/or high rate training conditions.

In a study of programmed instruction, Crosbie and Kelly (1994) manipulated the delay of time between the presentations of questions. They found that when a 10-second delay was imposed after each question, effectively slowing down subjects rate of responding, subject's performance improved relative to conditions of no delay between questions. Although the content of training in Crosbie and Kelly's study was very different from that of the current study, mainly with respect to the complexity of the tasks, their data showed that slowing subjects' responding may be beneficial to the outcomes of learning, a finding inconsistent with most literature on fluency (e.g., Lindsley, 1996a, 1996b). This brings up the question of the appropriateness of rate training, especially in the context of higher education, where most training involves complex conceptual skills.

In summary, rate of responding is a dependent variable that can be manipulated in either of two ways. First, with instruction, contingencies of reinforcement, or methods of presentation, such as Single- or Multi-trials, which impose varying degrees of constraints on responding that differentially affects rate. Second, rates can be increased with added practice. The former manipulation, however, seems to have little effect on quality of learning, and, consequently, the only condition under which high rates are correlated with better learning outcomes than low rates is when the difference in rate is brought about through difference in amount of practice. The available evidence, therefore, does not support the general use of rate building procedures (instructions, contingencies of reinforcement, methods for presenting stimuli) in training with adult learners, except perhaps to promote the efficiency of training.

Implications for Testing

The results of the Experiment 2 show that there were differences between the three methods of presentation used to evaluate performance during tests. While the Single- and Seven-trial methods indicated no change in performance between the Post Rate and the Retention tests, the responding to test stimuli presented as Multi-trial presentations decreased significantly between the two tests. As a slight decrement in performance is not unreasonable over a two-week period of no practice, the data suggest that the Multi-trial method for presenting the test stimuli provided a more sensitive way of measuring changes in performance across time than the Single- and Seven-trial presentations. Because of this differential sensitivity of the three methods for presenting test stimuli, it can be argued that to ensure an appropriate measure of the effectiveness of different training method, Multi-trials should be used instead of Single-trials.

Although the results of Experiment 2 clearly showed differences in test performance between Multi- and Seven-trials, it is surprising that these two methods of presentation did not correspond more closely. Experiment 1 showed that these two methods of presentation share some of the same features, especially those of high response rates, which can be traced to subjects' reading ahead. The only difference between these two methods was that in Seven-trials, every seventh response prevented subjects from reading ahead, and as such it slowed down the overall rate of responding. Because of this, it is possible that the characteristics of Seven-trials during testing were more similar to Single-trial than to Multi-trials, resulting in reduced sensitivity to changes in performance across time.

Future Research

The current study occasioned a number of questions that could serve as an impetus for further research. First, the results of Experiment 1 did not clearly indicate the extent to which subjects can read ahead when responding to stimuli presented in with the Multi-trial procedure. Although the data suggested that subjects might be reading ahead by more than one stimulus at a time, further research is needed evaluate this. It may, for example, be possible to manipulate the number of consecutively available stimuli relative to a target stimulus (e.g., one or two) and observe if it has effect on rate of responding. If subjects are reading ahead by more than one stimulus, conditions in which two stimuli are available following a target stimulus should allow for faster rates than conditions that only have one available consecutive stimulus.

Experiment 2 of the current study found no difference between the two training conditions, Single- and Multi-trials, which is inconsistent with previous research that has suggested that Single-trial training results in better learning than Multi-trial training (Oddsson & Chase, 1999). As mentioned above, this can possibly be accounted by the difference in practice criterion for the two studies, where it can be argued that subjects in the current study were responding at optimal levels which precluded finding difference between the two training conditions. This explanation can be evaluated in an experiment that parametrically manipulates the practice criterion, gradually bringing subjects' responding closer to optimal levels. According to the above speculations, such a preparation should show that at lower levels of training subjects undergoing Single-trials should outperform the Multi-trial subjects. A gradual increase in the practice criterion (and rates), however, should results in a gradual convergence of the quality of learning associated with Single- and Multi-trials.

It is worth pointing out that most studies of the effects of rate training, including the current one, used college students as subjects whereas the literature on fluency that emphasizes rate-building is primarily based on observations of children. It is, therefore, conceivable that there may be in interaction between subject populations and effects of rate on learning outcomes. In other words, it is possible that for younger learners, high rate training yields superior learning outcomes than low rate training. This can be examined by systematically replicating some of the experiments that have shown no effect of rate training with a younger subject population, such as pre-school children.

This would extend the generality of the current findings and make them directly applicable to the most common use of rate-training procedures.

Conclusions

The dissertation showed that the primary reason for differences in rate observed between responding to Single- and Multi-trials is that in the latter, subjects are able to read ahead, which facilitates response rate. The high rates of responding supported by Multi-trials also allow for a more efficient method of practice because more practice can be accomplished in a shorter period of time. Therefore, there may be conditions under which Multi-trial training has advantages over Single-trial training. The differences in efficiency between the Single- and Multi-trials, however, seem to be task specific because no differences were found in rates of responding to more complex tasks. Under such conditions the efficiency argument for using Multi-trials is negated.

In addition, this dissertation revealed no differences between the two training methods with respect to quality of learning when rates during training were close to asymptotic. Although these results clarified difference founds in previous research, they counter claims of superiority of Multi-trial training methods, which to date are unsubstantiated by empirical evidence. The findings of this and other related studies show that in the absence of difference in practice, high rates of responding are not important for the outcomes of learning, irrespective of training tasks and methods used for achieving those rates. The only potential advantage of rate training is that students may be able to practice more efficiently.

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Tables

Table 1

Experimental Phases for Subjects in Experiments 1.

Experimental Phases
I. Subject Selection Test
II. Pre-training
III. Speech Calibration
IV. Training to 85% accuracy
V. Rate-training: Multi-trials
VI. Testing: Alternating Treatments
a. Multi-trials (Baseline)
b. Single-trials
c. Added-trials
d. Seven-trials
a. Deleted-trials

Table 2

Performance Scores During Rate Training For All Subjects in Experiment 1.

Subject	Total # of timings	Total # of trials	Total # of correct trials	Mean accuracy
H61	141	4308	4142	96
H63	125	3621	3450	95
H64	82	2542	2314	91
H66	62	1924	1811	94
H67	63	1955	1837	94
Average	95	2870	2711	94

	Mean # of correct trials/timing	
Subject	Overall	Last 10 timings
H61	30	39
H63	28	34
H64	28	38
H66	29	38
H67	29	37
Average	29	37

Table 3

Average Duration of Responding in Milliseconds to Binary Numbers By Subject and Method of Presentation for All Subjects in Experiment 1.

	Method of Presentation						
						Mean	Mean
Subject	Single	Added	Seven	Multi	Deleted	Multi/Deleted	overall
H61	531	521	544	570	558	564	545
H63	398	385	415	404	403	404	402
H64	469	501	484	470	467	468	478
H66	377	356	397	421	396	409	389
H67	416	410	415	416	431	424	417

Table 4

The Discrepancy Between Average Difference in Latencies to High and Low Rate Methods of Presentation, and the Average Utterance Durations to Stimuli Presented with High Rate Methods, for All Subjects in Experiment 1. Times are Represented in Milliseconds.

Subjects	Difference in latencies	Utterance duration	Discrepancy
H61	610	564	46
H63	575	404	171
H64	592	468	124
H66	516	409	107
H67	595	424	171

Table 5

Experimental Phases for Subjects in Experiments 2.

Experimental Phases	
I.	Subject Selection Test
II.	Pre-training
III.	Speech Calibration
IV.	Testing: Pretest
V.	Training to 85% accuracy
VI.	Testing: Post Accuracy
VII.	Rate Training
	a. Single-trials (Condition 1)
	b. Multi-trials (Condition 2)
VIII.	Testing: Post Rate
IX.	Testing: Retention

Table 6

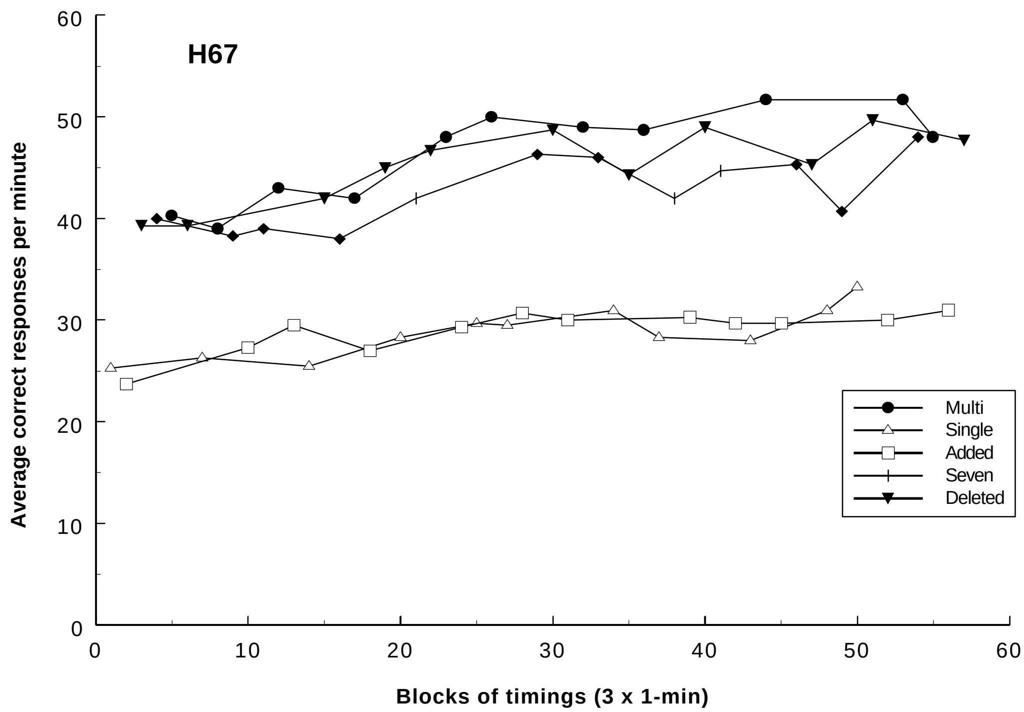
Mean Performance Scores and Standard Deviations of Subjects in the Single- and Multi-trial Rate-training Conditions of Experiment 2. The Standard Deviations are shown in parentheses.

	Type of training	
	Single-trials	Multi-trials
# of 1-min timings	148 (16.7)	116 (13.4)*
Accuracy	92 (3.2)	93 (1.8)
# of correct trials	3672 (127.4)	3728 (64.6)
# of incorrect trials	327 (127.4)	271 (64.6)
# of correct trials per timing	25 (2.8)	33 (3.5)*
# of incorrect trials per timing	2 (1.0)	2 (0.7)
# of correct trials: last 10 timings	28 (2.6)	40 (4.5)*
Latency to respond	1445 (254.1)	997 (245.8)*

* indicates significance at < .01

Figures

Figure 1. Rate of correct responding as a function of method of presentation for subject H67 in Experiment 1. The upper panel shows correct responses per minute for each one-minute timing. The lower panel shows the average rate of correct responding across three one-minute timings of each component.


H67
Average correct responses per minute
Blocks of timings (3 x 1-min)
Multi
Single
Added
Seven
Deleted
0
10
20
30
40
50
60

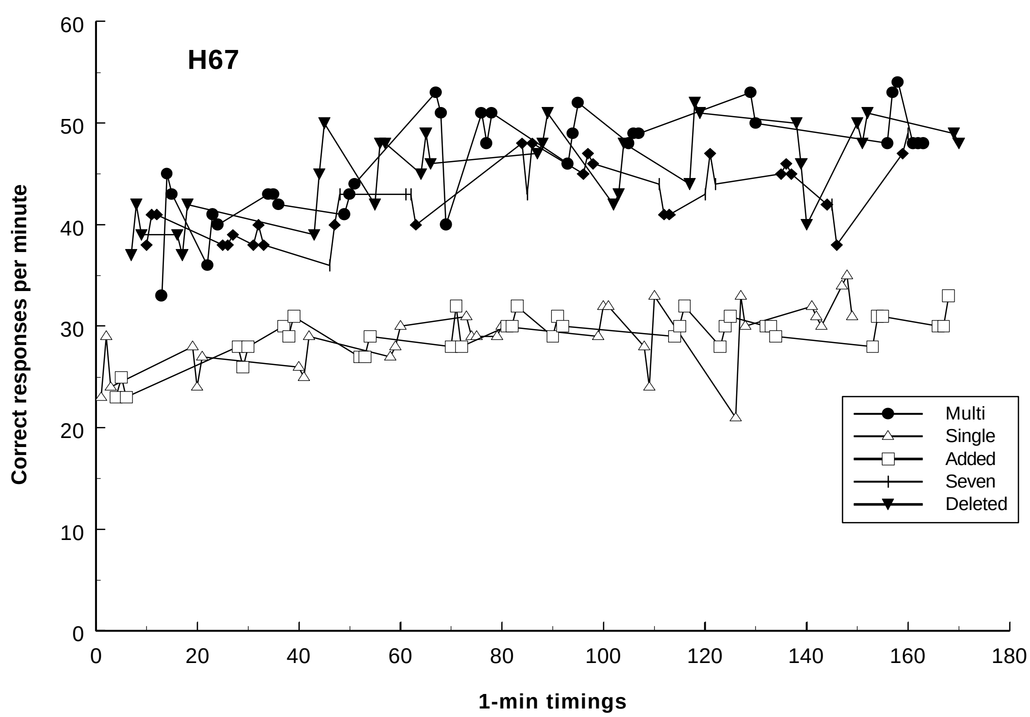

H67
Correct responses per minute
1-min timings
Multi
Single
Added
Seven
Deleted
0
20
40
60
80
100
120
140
160
180

Figure 2. Average Latency to Respond by Trial Number and Method of Presentation for Subject H67 in Experiment 1.

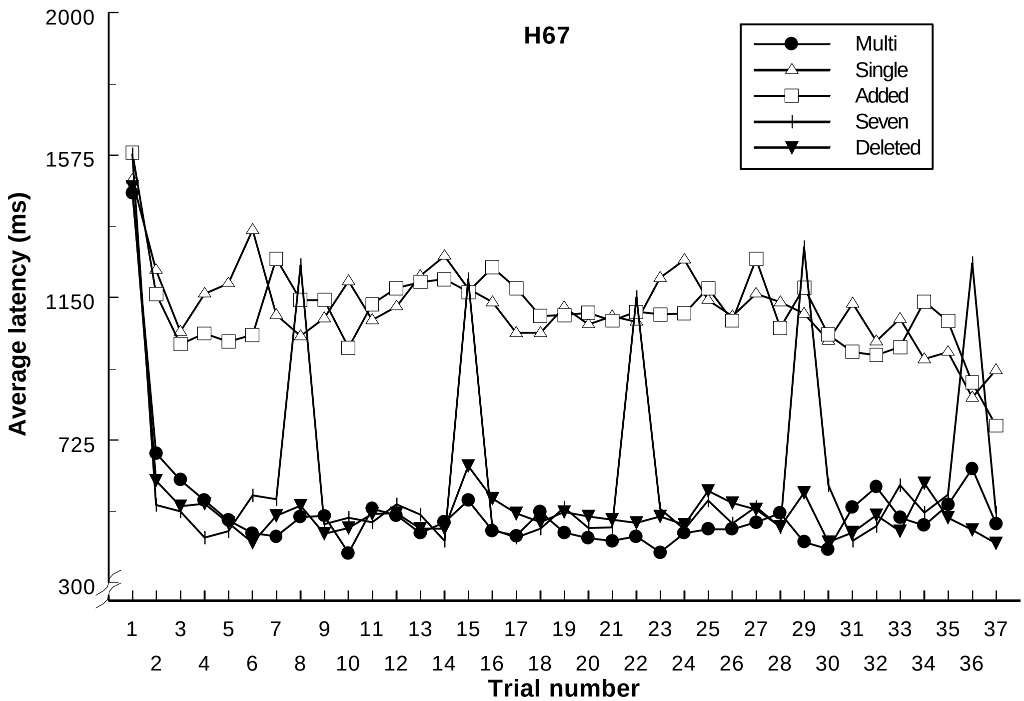
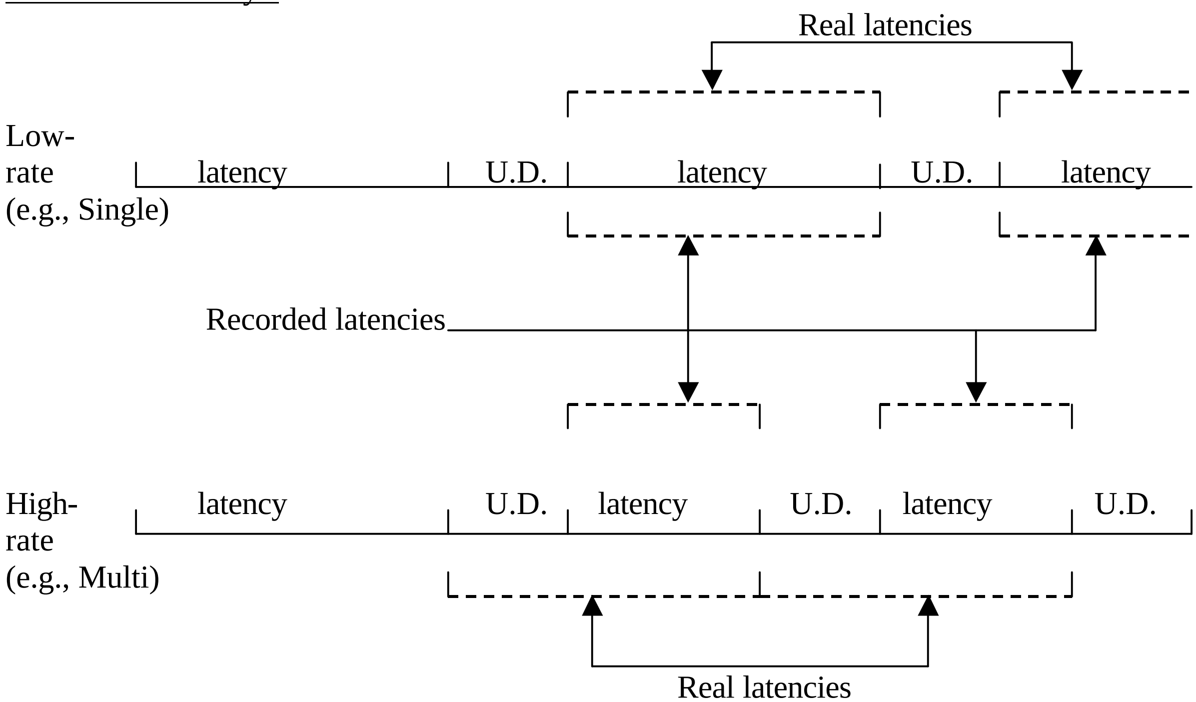

H67
Multi
Single
Added
Seven
Deleted
Average latency (ms)
2000
1575
1150
725
300
Trial number
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36

Figure 3. Real and recorded mean latencies and mean utterance durations (U.D.) to high- and low-rate methods of presentation. The two upper panels illustrated differences in recorded latencies when no technical delays (C) are assumed and the two bottom panels illustrate differences when technical delays are assumed.

No Technical Delays:



Technical Delays (C):

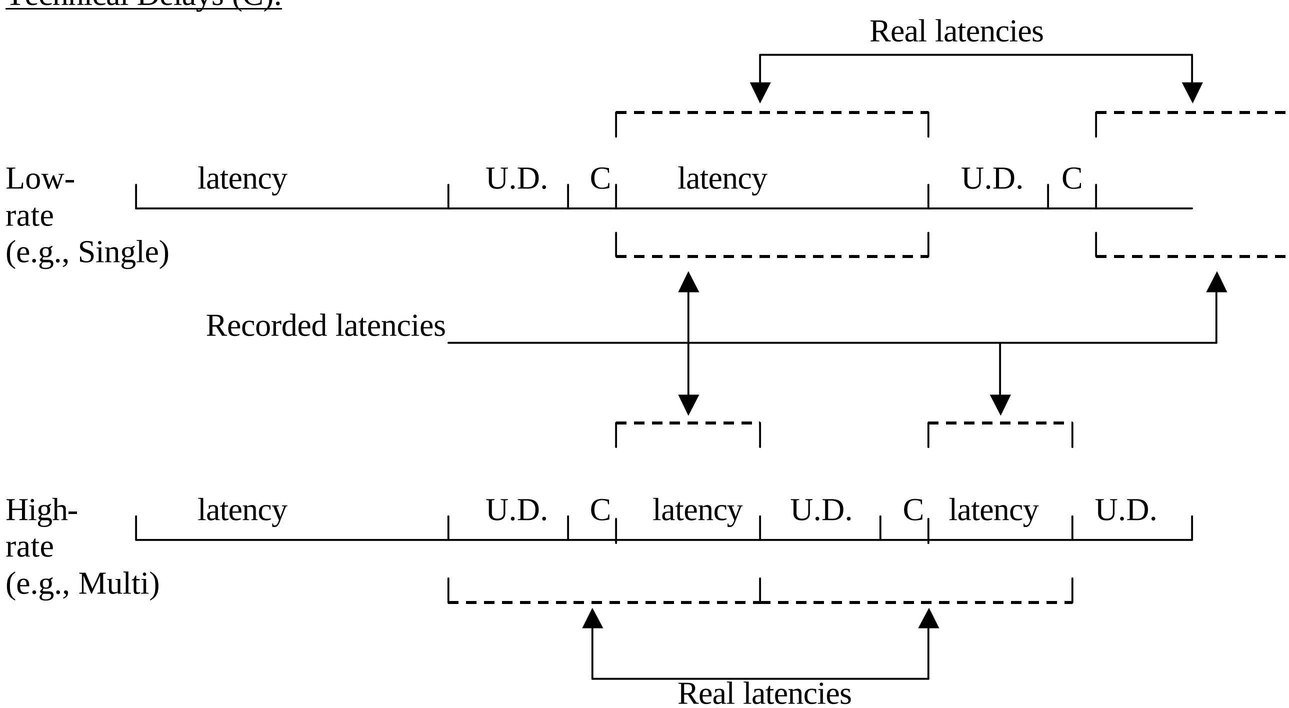
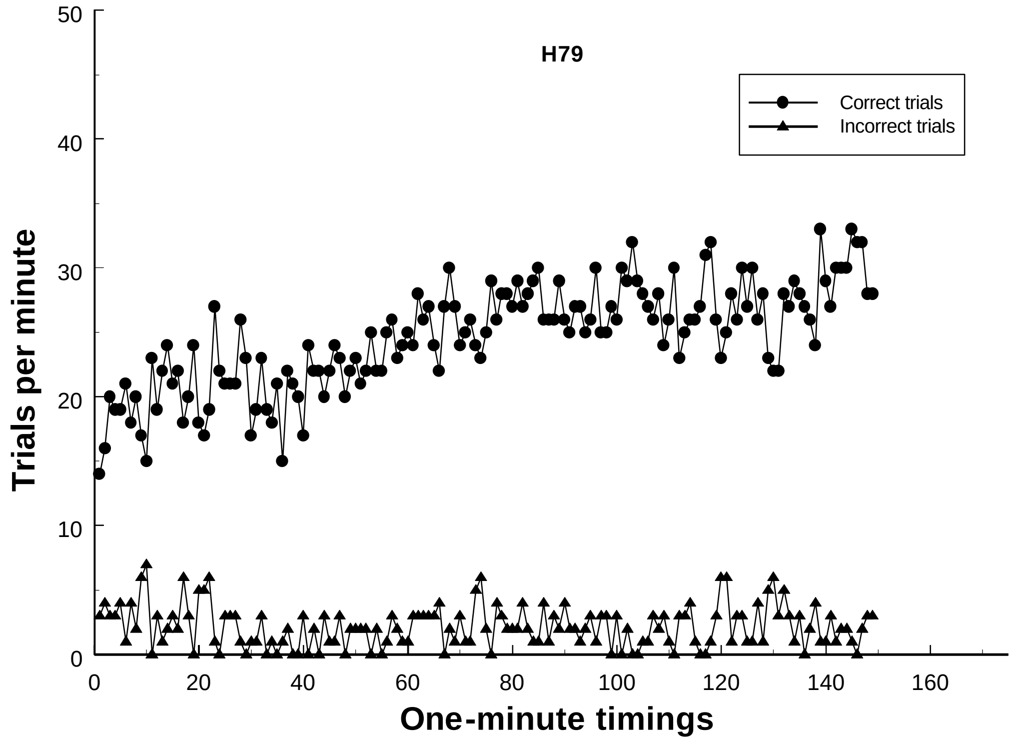


Figure 4. Rate of correct and incorrect responding as a function of training for a representative subject from each experimental group in Experiment 2. The upper panel shows Single-trial subject H79 and the lower panel shows Multi-trial subject H88 (Note: the x-axes are different).


H79
Correct trials
Incorrect trials
Trials per minute
One-minute timings
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160

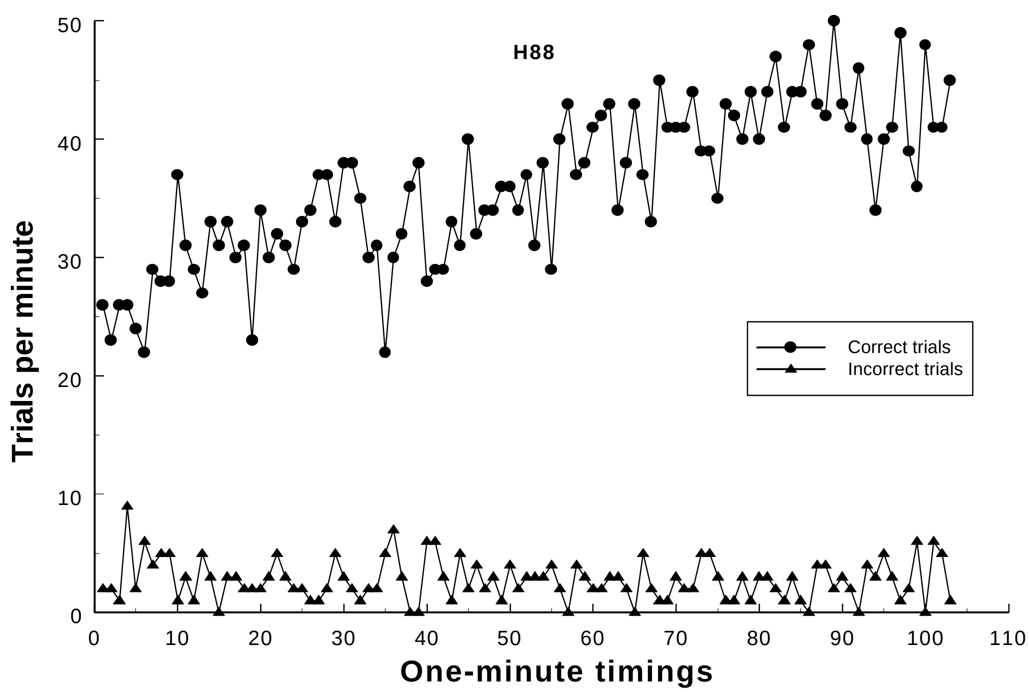
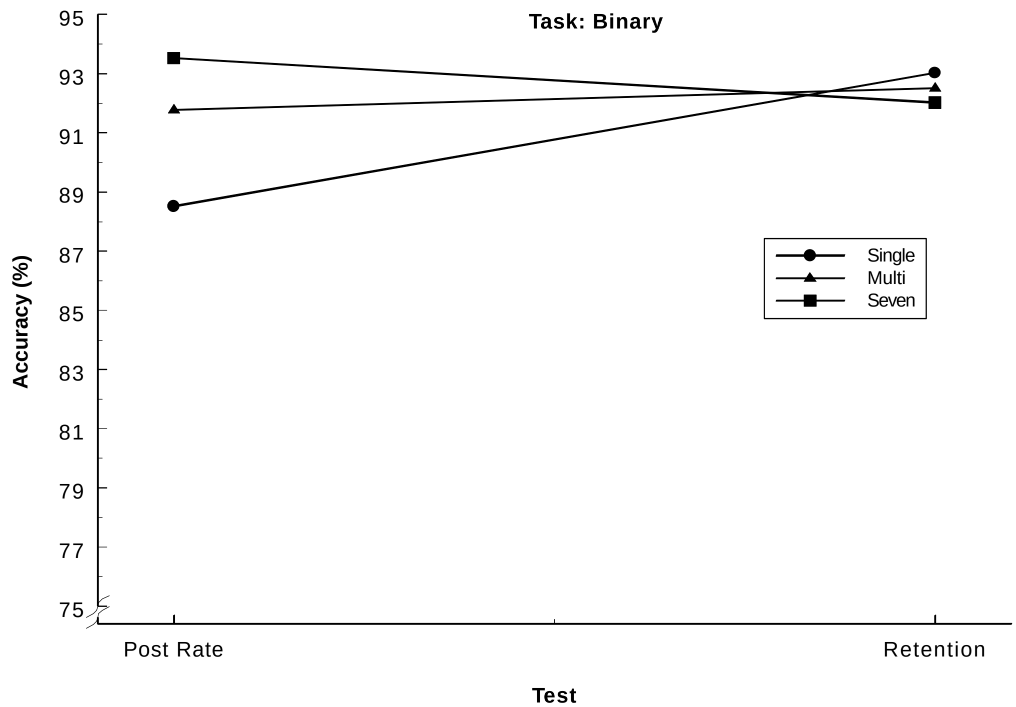

H88
Correct trials
Incorrect trials
Trials per minute
One-minute timings
0
10
20
30
40
50
0
10
20
30
40
50
60
70
80
90
100
110

Figure 5. Average accuracy of responding for all subjects in Experiment 2 to trained binary numbers and math problems presented in binary numbers on the Post Rate and Retention tests as a function of method of presentation and type of task. Circles represent Single-trials, triangles represent Multi-trials, and squares represent Seven-trials. The upper panel shows accuracy to binary numbers and the lower panel shows accuracy to math problems.


Task: Binary
Accuracy (%)
95
93
91
89
87
85
83
81
79
77
75
Post Rate
Retention
Test
Single
Multi
Seven

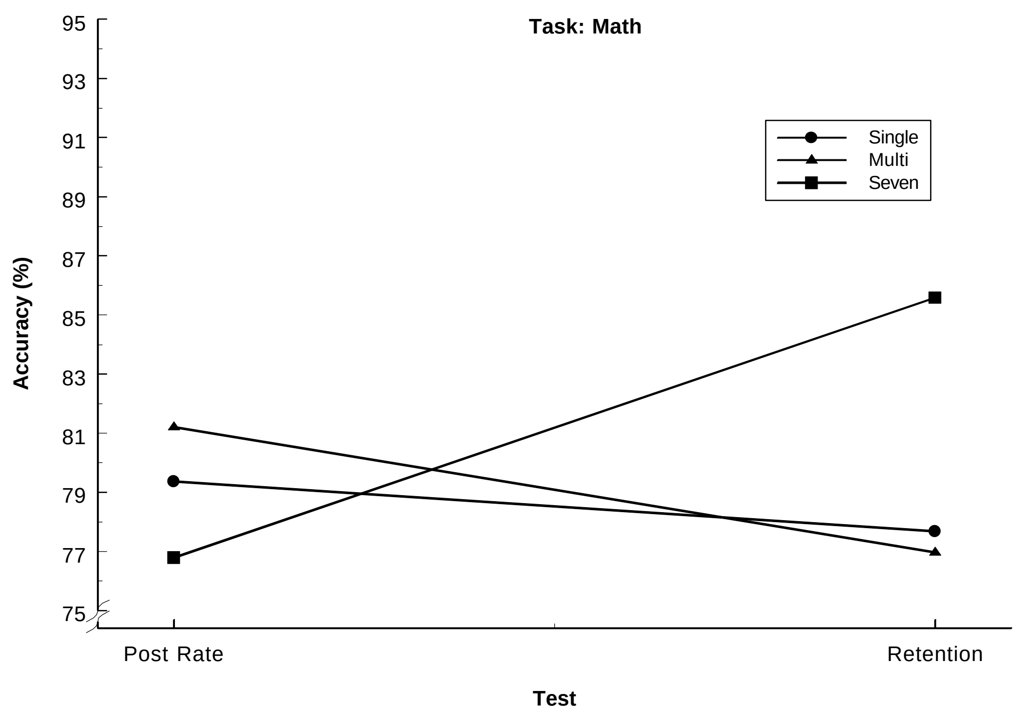
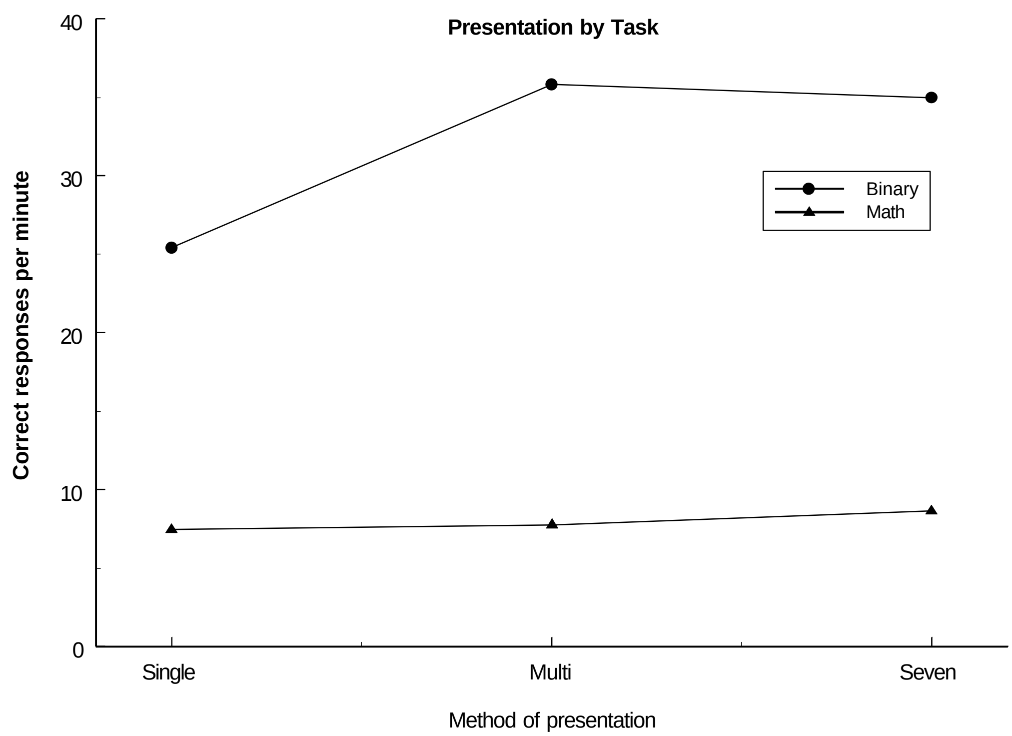
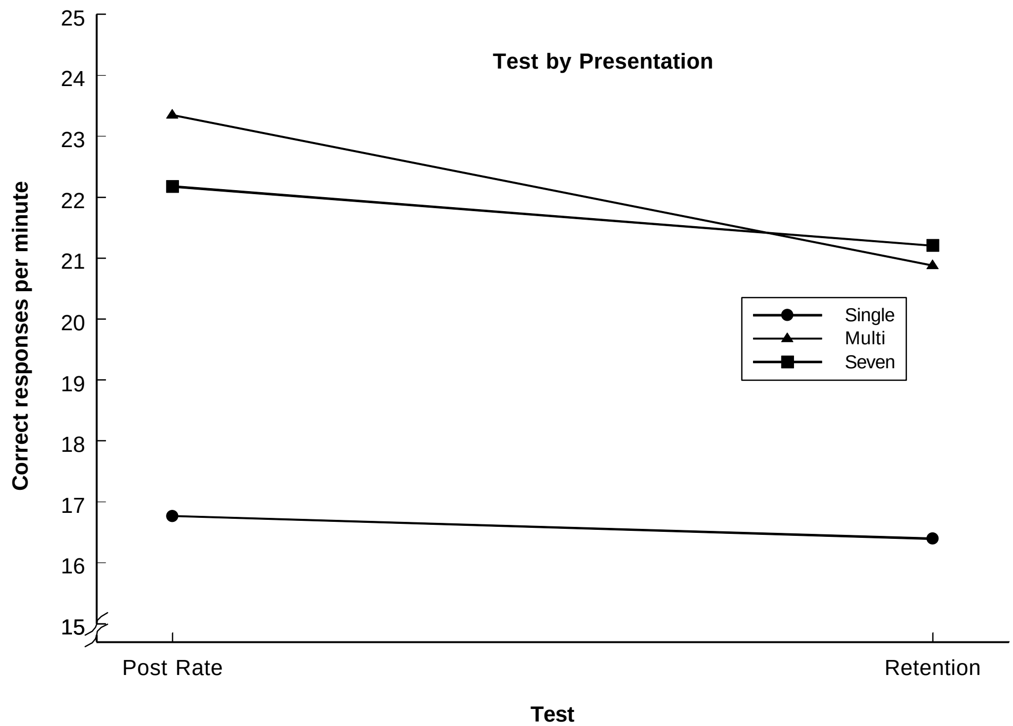

Task: Math
Accuracy (%)
95
93
91
89
87
85
83
81
79
77
75
Post Rate
Retention
Test
Single
Multi
Seven

Figure 6. Mean rate of correct responding for all subjects in Experiment 2 to binary numbers and math problems presented in binary as a function of method of presentation and type of task collapsed across the Post Rate and Retention tests. The circles represent binary numbers and the triangles represent math problems.



Presentation by Task
Correct responses per minute
40
30
20
10
0
Binary
Math
Single
Multi
Seven
Method of presentation

Figure 7. Mean rate of correct responding for all subjects in Experiment 2 as a function of method of presentation and type of test collapsed across type of task (Binary and Math). The circles represent Single-trials, the triangles represent Multi-trials, and the squares represent Seven-trials.



Test by Presentation
Correct responses per minute
25
24
23
22
21
20
19
18
17
16
15
Single
Multi
Seven
Post Rate
Retention
Test

Appendices

Appendix A. Subject recruitment form.

Subject Recruitment Sign-up Form

Name of Study: Fluency and Computerized 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 1999-2000 academic year. Participants have the opportunity to earn approximately $6 per hour of participation, which includes $1 attendance bonus for attending each scheduled session. No extra credit will be given for participation. Participants are required to attend 1-hour sessions, 4-5 times each week. It will take approximately 5-15 one-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. ____________	____________	____________
12. ____________	____________	____________
13. ____________	____________	____________
14. ____________	____________	____________
15. ____________	____________	____________
16. ____________	____________	____________
17. ____________	____________	____________

18. ______________________ ____________________ ____________________

19. ______________________ ____________________ ____________________

20. ______________________ ____________________ ____________________

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.

Informed Consent Form

A Comparison of the Effectiveness of Five Computerized 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 by Finnur Oddsson to fulfill requirements for a doctoral degree in Psychology at West Virginia University.

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

Description of Procedures: During this study I will learn to translate binary numbers into decimal numbers. The training methods used involve presenting the numbers 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 about 5-15 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. I understand that I may gain up to $5 for my performance during each experimental session and $1 attendance bonus for each session if I do not miss any sessions without notifying the experimenter. I understand that if I miss one 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. 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: $1x2^2 + 1x2^1 + 0x2^0 = 4 + 2 + 0 = 6$. Let's look at a few more examples:

Binary	Calculation	Decimal equivalent
1	$1x2^0 = 1$	1
11	$1x2^1 + 1x2^0 = 2 + 1$	3
101	$1x2^2 + 0x2^1 + 1x2^0 = 4 + 0 + 1$	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).

Appendix E.

Rate of Correct Responding for Each Timing as a Function of Method of Presentation for All Subjects in Experiment 1.

	H61					H63				
Timing	Single	Added	Multi	Seven	Deleted	Single	Added	Multi	Seven	Deleted
1	25	26	39	30	31	20	27	32	25	28
2	27	28	38	35	41	22	27	33	30	35
3	23	29	33	37	34	24	22	26	33	31
4	28	28	36	37	36	27	22	36	32	26
5	25	26	37	36	34	25	23	30	33	26
6	24	26	39	37	32	26	23	34	32	29
7	29	28	35	31	29	25	24	39	30	38
8	25	28	30	31	41	26	31	32	38	43
9	28	26	36	38	38	26	29	36	39	41
10	28	27	41	38	41	27	25	38	35	42
11	28	29	40	36	43	28	27	33	33	36
12	27	28	38	39	33	22	25	41	33	35
13	26	28	42	36	41	26	25	35	37	35
14	27	28	38	34	39	31	25	36	40	29
15	28	28	40	39	39	29	23	35	32	44
16	31	23	37	41	32	30	25	42	36	40
17	26	27	38	44	40	28	28	46	40	44
18	25	29	34	39	42	28	26	36	41	43
19	27	29	46	41	40	25	29	34	38	40
20	27	28	39	34	40	30	22	47	39	43
21	26	29	40	41	35	27	25	43	37	43
22	28	23	35	34	40			42		41
23	27	28	37	31	42			40		
24	21	27	42	31	41			36		
25	30	26	40	41	41					
26	32	24	34	43	47					
27	27	22	42	42	45					
28	30	31	45	41	39					
29	28	32	38	43	43					
30	32	31	41	39	44					
31	27	28	38	39	45					
32	28	31	42	39	35					
33	27	28	41	33	45					
34	29	29	35	36						
35	30	30	41	36						
36	31	31	41	43						
37	30	31	45	41						
38	30	32	41	36						
39	29	31	43	43						
40	31			42						
41	32									

	H64					H66				
Timing	Single	Added	Multi	Seven	Deleted	Single	Added	Multi	Seven	Deleted
1	24	24	33	33	36	29	32	41	38	39
2	26	26	41	37	41	29	26	42	40	47
3	25	25	40	35	42	29	30	42	37	42
4	29	23	43	31	26	28	32	47	41	44
5	27	25	40	33	35	30	32	42	36	46
6	23	24	43	31	38	34	34	45	44	44
7	25	28	41	40	43	30	31	50	48	51
8	28	24	40	35	45	33	31	50	47	53
9	28	29	44	39	45	36	35	50	48	51
10	33	32	44	41	44	37	35	54	42	53
11	33	30	46	48	48	36	33	47	47	49
12	28	32	40	49	50	36	37	52	48	48
13	27	31	42	49	48	36	38	52	52	39
14	30	30	39	45	50	39	35	53	48	44
15	30	36	49	37	40	34	37	52	50	52
16	30	35	44	50	48	39	39	53	53	56
17	32	34	45	42	46	40	39	56	52	57
18	32	26	44	42	47			54	42	53

	H67				
Timing	Single	Added	Multi	Seven	Deleted
1	23	23	33	38	37
2	29	25	45	41	42
3	24	23	43	41	39
4	28	28	36	38	39
5	24	26	41	38	37
6	27	28	40	39	42
7	26	30	43	38	39
8	25	29	43	40	45
9	29	31	42	38	50
10	27	27	41	36	42
11	28	27	43	40	48
12	30	29	44	43	48
13	31	28	53	43	45
14	29	32	51	43	49
15	29	28	40	40	46
16	29	30	51	48	47
17	30	30	48	43	48
18	29	32	51	48	51
19	32	29	46	45	42
20	32	31	49	47	43
21	28	30	52	46	48
22	24	29	48	44	44
23	33	30	49	41	52
24	21	32	49	41	51
25	33	28	53	43	50
26	30	30	50	47	46
27	32	31	52	44	40
28	31	30	48	45	50
29	30	30	53	46	48
30	34	29	54	45	51
31	35	28	48	42	49
32	31	31	48	42	46
33		31	48	38	48
34		30		47	
35		30		49	
36		33			

Appendix F.

Average Latencies to Respond by Trial Number and Method of Presentation for All Subjects in Experiment 1.

	H61					H63				
Trial #	Single	Added	Multi	Seven	Deleted	Single	Added	Multi	Seven	Deleted
1	1646	1736	1557	1721	1672	1944	1664	1715	1680	1768
2	1287	1210	666	548	713	1405	1355	804	503	707
3	1275	1154	792	548	688	1484	1248	758	474	555
4	1215	1216	685	657	631	1596	1196	657	565	502
5	1185	1150	626	609	625	1531	1251	618	618	590
6	1191	1196	634	687	601	1525	1295	707	693	542
7	1156	1240	550	668	678	1293	1460	859	618	629
8	1242	1430	617	1374	896	1224	1444	822	1575	917
9	1054	1213	547	724	551	1473	1533	666	824	535
10	1158	1165	645	507	651	1253	1484	778	950	717
11	1230	1162	531	490	668	1397	1347	760	633	739
12	1222	1165	696	551	660	1395	1272	527	816	682
13	1266	1160	512	574	713	1457	1549	616	584	747
14	1328	1207	532	547	526	1374	1397	806	806	497
15	1279	1202	700	1269	573	1497	1403	813	1578	839
16	1174	1285	572	707	493	1740	1324	964	845	617
17	1169	1155	586	644	580	1235	1586	756	680	864
18	1194	1182	562	585	561	1431	1622	749	1010	657
19	1211	1202	611	609	678	1321	1285	792	631	662
20	1161	1314	702	620	585	1539	1510	740	678	707
21	1178	1367	605	594	505	1248	1397	918	824	680
22	1217	1197	505	1304	560	1420	1400	577	1408	1022
23	1241	1302	641	687	618	1195	1379	753	798	947
24	1307	1151	713	592	638	1267	1573	673	654	610
25	1288	1261	677	601	616	1212	1527	737	1015	1164
26	1082	1091	491	513	525	1352	1258	710	693	647
27	1187	1156	599	683	548	1504	1497	946	667	1107
28	1238	1211	594	589	496	1256	1273	662	602	654
29	1235	1184	515	1278	644	1219	1300	845	1550	667
30	1162	1051	544	543	546	1181	1460	646	607	694
31	965	968	528	568	555	1220	1110	831	942	806
32	1264	956	583	519	558	1017	797	1049	723	651
Means	1219	1207	635	722	642	1381	1381	789	851	754

Trial #	H64 Single	H64 Added	H64 Multi	H64 Seven	H64 Deleted	H66 Single	H66 Added	H66 Multi	H66 Seven	H66 Deleted
1	1327	1148	1395	1292	1146	1270	1239	1297	1484	1261
2	1075	1154	495	447	407	1002	910	394	482	681
3	1091	1132	401	478	647	1083	1019	333	498	425
4	1128	1058	455	414	505	918	1035	455	592	458
5	1091	1135	654	433	382	1008	851	400	452	501
6	1062	1066	555	483	497	924	961	425	476	452
7	1109	1041	382	488	542	960	1044	507	418	531
8	1060	1489	513	1378	629	915	1123	370	1230	614
9	1034	1115	367	457	507	1008	910	339	397	391
10	1133	1261	513	523	402	1086	971	577	388	421
11	1219	1049	534	459	425	1012	888	415	458	501
12	1039	1052	531	351	625	982	922	290	425	385
13	1149	1027	419	480	430	1057	955	440	550	403
14	1261	1096	503	385	345	1154	971	367	501	400
15	1122	967	521	1073	505	1047	1037	492	1019	498
16	1177	1286	536	492	490	1021	1147	443	473	516
17	1117	1016	552	418	482	979	1002	458	428	382
18	1143	1165	571	416	472	869	895	479	623	498
19	1044	948	429	409	462	934	908	357	501	482
20	1081	1214	523	535	455	1057	976	440	507	440
21	1318	1038	377	461	402	1044	1037	425	409	476
22	1091	1212	510	848	552	982	937	403	974	492
23	1107	1118	385	707	425	1066	1054	357	601	571
24	1167	1091	573	495	460	1176	957	583	547	452
25	1167	1124	597	402	406	960	1138	492	565	602
26	994	1191	445	373	408	1047	927	345	470	449
27	1082	1258	555	488	560	1076	1008	425	501	540
28	1050	999	471	397	408	895	960	519	495	577
29	1270	1189	615	1135	597	1151	1037	568	1352	486
30	1106	1004	416	437	466	1099	1066	470	501	415
31	1016	1030	453	433	435	1039	963	470	406	461
32	1117	1023	589	464	476	998	1029	394	504	431
33	1012	897	636	433	414	925	824	788	510	449
34	842	1126	539	590	437	1319	870	458	446	431
35	916	1044	594	607	602	890	1122	373	724	644
36						989	920	501	1065	504
37						910	868	425	430	397
38						855	934	595	598	479
39						838	1066	455	584	504
40						1264	797	397	601	553
41						769	1456	611	667	522
Means	1106	1108	532	562	497	1014	994	471	606	504

	H67				
Trial #	Single	Added	Multi	Seven	Deleted
1	1503	1584	1464	1578	1482
2	1233	1162	686	531	605
3	1049	1012	606	514	528
4	1162	1044	546	434	536
5	1193	1020	486	454	478
6	1353	1039	448	561	420
7	1099	1267	438	550	500
8	1035	1143	496	1248	530
9	1089	1143	500	474	446
10	1200	1001	388	493	463
11	1083	1131	521	481	505
12	1125	1178	501	534	506
13	1216	1197	448	503	461
14	1276	1206	481	426	461
15	1178	1168	546	1206	648
16	1137	1241	455	459	551
17	1046	1178	440	433	506
18	1046	1096	511	460	481
19	1123	1099	450	524	511
20	1071	1105	433	463	498
21	1095	1082	425	465	488
22	1078	1108	438	1154	478
23	1209	1100	390	521	498
24	1264	1103	448	459	473
25	1143	1178	460	545	575
26	1095	1082	460	476	538
27	1163	1265	480	526	520
28	1137	1061	508	465	468
29	1103	1181	421	1302	568
30	1022	1040	400	590	421
31	1134	989	525	426	450
32	1021	979	586	470	501
33	1087	1003	495	590	453
34	966	1139	471	509	596
35	989	1081	533	562	495
36	852	897	640	1253	458
37	934	769	476	509	416
Means	1122	1110	514	626	527

Appendix G.

Analysis of Variance for Accuracy of Responding During Testing in Experiment 2.

Source	SS	df	MS	F
Training	154.92	1	154.92	.56
Presentation	229.96	2	114.98	1.02
Training x Presentation	68.94	2	34.47	.31
Test	92.32	1	92.32	.38
Training x Test	13.98	1	13.98	.06
Task	9521.69	1	9521.69	51.99**
Training x Task	94.65	1	94.65	.52
Presentation x Test	259.34	2	129.67	1.08
Training x Presentation x Test	680.90	2	340.45	2.84
Presentation x Task	17.52	2	8.76	.08
Training x Presentation x Task	62.15	2	31.07	.29
Test x Task	2.43	1	2.43	.01
Training x Test x Task	118.88	1	118.88	.71

Presentation x Test x Task	869.17	2	434.58	4.47*
Training x Presentation x Test x Task	72.67	2	36.33	.37

Note:

* $p < .05$. ** $p < .01$.

Appendix H.

Analysis of Variance for Rate of Correct Responding During Testing in Experiment 2.

Source	SS	df	MS	F
Training	4.71	1	4.71	.04
Presentation	1430.40	2	715.20	45.56**
Training x Presentation	91.00	2	45.50	2.90
Test	111.85	1	111.85	6.88*
Training x Test	1.85	1	1.85	.11
Task	33449.69	1	33449.69	1434.49**
Training x Task	9.48	1	9.48	.41
Presentation x Test	86.93	2	43.47	3.44*
Training x Presentation x Test	73.88	2	36.94	2.93
Presentation x Task	1086.79	2	543.40	41.73**
Training x Presentation x Task	53.21	2	26.61	2.04
Test x Task	58.22	1	58.22	3.92
Training x Test x Task	4.18	1	4.18	.28

Presentation x Test x Task	40.03	2	20.02	1.87
Training x Presentation x Test x Task	34.49	2	17.24	1.61

Note:

* $p < .05$. ** $p < .01$.