Shaping and Chaining Human Limb Movement Using a Video Tracking System

by

Darlene E. Crone-Todd

A Thesis
Submitted to the Faculty of Graduate Studies
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Department of Psychology
University of Manitoba
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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

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Darlene E. Crone-Todd

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Abstract

Shaping and Chaining are both effective in training new behavior. Shaping, or the reinforcement of successive approximations to a target response, is used to develop novel responses or reestablish responses no longer occurring. Chaining is used to develop fixed sequences of responses. The combination of the two procedures was examined using twelve participants (8 men and 4 women) who were randomly assigned to one of three chaining comparisons in an individual organism design: Forward Chaining (FC) versus Backward Chaining (BC), FC versus Total Task Chaining (TTC), or BC versus TTC. A video tracking system recorded the coordinate position of a participant's hand in three-dimensional space, relative to the position of three targets randomly selected by the computer. Contingent upon contact with a shaping sphere around the current target in the chain component being trained, reinforcement in the form of a computer-emitted tone occurred. Upon completion of a training component, a different tone and points were presented as reinforcement. Reinforcement amount was equated between FC, BC, and TTC procedures, and a test phase requiring 5 repetitions of the sequence to demonstrate that learning took place. The following was found: (a) in the FC - BC comparison BC was generally more effective than FC, (b) in the FC - TTC comparison FC was generally more effective than TTC, but (c) in the BC - TTC comparison there were fewer differences between BC and TTC. The outcomes for the FC versus BC and the BC versus TTC comparisons are in contrast to the literature, and require further investigation. The automated chaining procedures used in this study show promise as a method to be used in a rehabilitative setting.

Introduction

Often we take for granted the most basic activities humans engage in on a daily basis. For instance, dressing ourselves, making a bed, and moving our arms are behaviors we engage in almost without a second thought. However, there are populations of individuals for whom these behaviors are indeed a challenge. Training of such challenged individuals has used at least two gradual change procedures (Martin & Pear, 1996): shaping and chaining[1].

Shaping is the reinforcement of successive response approximations toward a targeted behavior. Chaining is the establishment of a series of responses that occur in a fixed sequence: each response (until the final one) in the sequence produces a discriminative stimulus (i.e., a "cue") for the subsequent response in the chain. Shaping and chaining share some similar components, but differ from each other in application. Traditionally, shaping has been used either to develop a novel (i.e., low probability) response (e.g., Crone-Todd & Pear, 1996; Pear, Crone-Todd, & Besko, 1996), or re-establish a response that is no longer occurring (e.g., Taub, Crago, Burgio, Groomes, Cook, DeLuca, & Miller, 1994). Chaining has been used to link responses together, as in the acquisition of keyboard skills (Ash & Holding, 1990). Shaping procedures are implicit in many of the studies using various chaining techniques, but to date there has not been any systematic study of chaining procedures that explicitly incorporate an effective shaping procedure.

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[1] Appendix A contains detailed definitions of key terms for reference purposes.

Research in Shaping and Chaining

Shaping. In order to begin a systematic study of spatial properties of behavior, Pear and Legris (1987) used two cameras attached to a computer to track, record, and shape the three-dimensional position of a pigeon's head in an operant chamber. Information regarding the position of the head, and the relative distance from an invisible, computer - defined target determined the size of a three-dimensional shaping sphere at any given moment. Reinforcement in the form of food delivery was contingent upon the bird's head making contact with a computer - defined shaping sphere concentric the target. The shaping sphere contracted toward the target according to a forward stepsize (FSS), defined as the criterion by which responding must shift closer to target location to produce reinforcement, and expanded back out according to a backstep rate (BSR), defined as the amount by which the criterion for a reinforced response relaxes, per unit of time in which no reinforcement occurs. Once target behavior was established, the BSR was set to zero, thereby providing reinforcement for target hits only. Thus, two distinct stages occurred in the above shaping procedure: (a) The shaping sphere contracted, contingent upon contact, to a region close to the target sphere, and (b) target sphere contact occurred.

The use of a computer program to carry out shaping (or other procedures) relies upon a finite series of steps that the program executes (Aho, Hopcroft & Ullman, 1983) to determine when a particular response has occurred that produces a reinforcer. The series of steps used in such computer procedures are referred to as computer algorithms. Thus, when discussing a particular shaping or chaining procedure which has used a computer algorithm, I may refer to these as algorithmic shaping or algorithmic chaining, respectively.

Midgely, Lea, and Kirby (1989) conducted two studies on algorithmic shaping of a complex response in rats, and compared it to hand-shaping (i.e., carrying out the shaping procedure without the aid of a computer program). The computer algorithm included a hierarchy of 5 steps, each on an Fixed Ratio (FR) schedule (i.e., a schedule of reinforcement that requires a fixed number of responses to be emitted prior to the presentation of reinforcement). An initial low-value FR was defined for each response, and after a given number of reinforcements were provided for that response, the FR value was increased by a constant amount. After an amount of time elapsed without reinforcement, a return to the next lowest hierarchical response occurred, in which the original FR schedule was once again in place. Results indicated that rats' behavior could be shaped to deposit ball bearings down a hole in the floor of an operant chamber using the above algorithm. Further, the algorithmic shaping procedure itself was similar in effectiveness to that of the hand-shaping procedure, with the former producing more stable behavior than the latter. This finding was considered to be due to the consistent high reinforcement and lack of extinction produced by the algorithmic procedure.

In an attempt to gather cross-species evidence for the effectiveness of the shaping procedure used by Pear and Legris (1987), Pear et al. (1997) shaped the movement of a hand-held pointer by humans in three-dimensional (3D) space. The main purpose of this research was to begin to systematically test varying levels of the FSS and BSR parameters in the shaping process. Participants' movement of a hand-held pointer within a metal cube was shaped in a similar manner as the pigeons in the Pear and Legris study. By using the shaping sphere once again (FSS = 5 mm; BSR = 10 mm/5 s), and then removing the sphere from test trials, Pear et al. showed that not only was a novel response (i.e., one with a very low probability) shaped using this method, but that the position of a previously learned target could be located again without the shaping sphere. Subsequent experiments determined that: (a) a relatively small FSS (5 mm) was more effective than a larger stepsize (FSS = 100 mm), and (b) a relatively moderate BSR (10 mm/5 s) was more effective than either a zero BSR or a faster BSR (30 mm/1 s).

These findings provide an impetus for future work on limb rehabilitation movement. For instance, it may be possible to improve the movement of affected limbs in populations of individuals with cerebral palsy (see Eckhhouse, Leonard, Zhuang, & Maulucci, 1994), or in stroke victims who can use their limbs, but have learned not to (see Taub et al., 1994). When the responses in one limb are faster (or more fluent), than in another, consequences that may reinforce behavior from that limb occur more often and more rapidly. Thus, the environment may select for non-affected limb use, thereby decreasing the probability of using the affected limb. Through a process of "using the good limb" more often, and "using the affected limb" less often, eventually use of the affected limb decreases to the point where it no longer occurs. With appropriate training procedures, this process may be counteracted.

Crone-Todd and Pear (1997) developed a computer game using a shaping algorithm similar to the one in the Pear et al. (1997) study to continue systematically studying the combined effects of FSS and BSR. The environment was a two-dimensional computer screen in which movement of a mouse cursor closer to a computer-defined target was reinforced with a tone. A shaping circle, concentric to the target, contracted and expanded according to various combinations of FSS and BSR. Crone-Todd and Pear systematically replicated and extended the findings of Pear et al. (1996) in a series of three experiments which compared a smaller and larger FSS, combined with a zero, moderate, or fast BSR. The overall findings indicated that: (a) the smaller FSS was more effective than the larger FSS and (b) the moderate BSR was more effective than either a zero BSR or a faster BSR.

Thus, an algorithmic shaping procedure which combines a small FSS and moderate BSR appears to be extremely effective in shaping behavior. The present study investigated chaining in three spatial dimensions, with shaping parameters previously found to be effective held constant.

Chaining. Research in chaining has not been as systematic as that carried out on shaping. However, progress in that direction is occurring. There is a wealth of literature on single-procedure designs, in which only one form of chaining has been investigated. For instance, TTC has been demonstrated as effective for training mentally-challenged individuals to dress themselves (Azrin, Schaeffer, & Wesolowski, 1976), to develop bussing skills in a full service restaurant (Certo, Mezzullo, & Hunter, 1985), to initiate, sustain, and terminate playing time on a video game (Duffy & Nietupski, 1985). The FC method has been demonstrated to be effective in training a profoundly retarded blind person to respond quickly to a fire alarm (Cohen, 1984), master mathematical components of change computation (Cuvo, Veitch, Trace, & Konke, 1978), develop bed making activity (McWilliams, Nietupski, & Hamre-Nietupski, 1990), and master the components in premeal, meal, and postmeal chains of behavior in an institutional setting (Wilson, Reid, Phillips, & Burgio, 1984). BC has been shown to be effective in training independent walking skills (Gruber, Reeser, & Reid, 1979) and bed-making activity (Martin, England,

& England, 1971). A review by Mountjoy and Lewandowski (1984) of procedures for training a horse to fetch a glove and return it to its owner indicate that the BC procedure was known as an effective means of training response sequences in the 19th century, despite the fact that the procedure had not yet been identified through behavior analysis.

More systematic studies that have been done involve comparisons of at least two of the three chaining procedures. For instance, FC and BC have been compared in pigeons (Piscareta, 1982), and in the development of keyboard skills in undergraduate students (Ash & Holding, 1990). Piscareta found no difference in observed error rates between FC and BC when training four white Carneaux pigeons on two four-link chains. However, he did observe that the acquisition of the first chain interferes with the acquisition of the second chain. Ash and Holding suggested that no clear difference exists between FC and BC evident in the literature. In training 24 quarter notes played singly (grouped into three sets of eight), they assessed the number of melodic and timing errors among the participants. Melodic and timing errors were higher in TTC than in either FC or BC.

Comparisons of BC and TTC have been carried out in at least two studies. Spooner (1984) studied the procedures used to train the assembly of a gate valve and a drain by severely and profoundly retarded persons. Reinforcement in the form of praise and handshake, eating pudding, or looking at books was presented for each component of the chain. Physical guidance prompts, gestural prompts and verbal prompts (i.e., prompts are "cues" that supplement training, which are not part of the final, desired behavior) were faded, and errors reduced overall during the course of training the tasks. TTC and BC were equally effective, and Spooner suggested that the fact that there was more training than in previous studies could be the reason. The TTC procedure appeared to produce a greater rate of behavior change per unit time. Thus, to determine which procedure to use, one should consider the amount of training required to criterion and the rate of behavior change (i.e., the amount of behavior change per time spent in training).

Zane (1981) compared the effects of feedback only (referred to as "Postguidance) with the effects of prompts and feedback (referred to as "Preguidance") on responding under BC and TTC procedures. Moderately and severely retarded participants assembled four 9-part assemblies (e.g., carburetors and bicycle brakes) in all four procedures. Auditory, visual, and tactile prompts were faded during the training sessions, and were controlled such that each preguidance procedure had a similar number of prompts. The time spent to acquire the chain and amount of guidance indicate that the TTC preguidance procedure was the most effective. The number of errors was highest in both TTC procedures; however, preguidance resulted in fewer errors than postguidance in the moderately retarded population. Conversely, the highest number of errors occurred during the BC procedure for the severely retarded group.

Walls, Dowler, Haught, and Zawlocki (1984) investigated the effects of FC and TTC using progressive prompt delays. Vocational rehabilitation clients completed four different 12-part assemblies (electric drill, lawn mower machine, bicycle brake, and electric mixer). Each time a correct response occurred, the delay between the presentation of the discriminative stimulus and a prompt was increased. The number of errors, prompts provided, and seconds of training time were assessed in four conditions: TTC with 1s progressive delay (i.e., 1s vs. 3s vs. 5s), TTC with unlimited delay (i.e., no prompt occurs on subsequent trials unless an error occurs), FC with progressive delay and FC with unlimited delay. Main effects were found for prompt delay (progressive was more effective than unlimited), and a significant interaction was found between training sequence and prompt delay interaction. The TTC procedure with unlimited delay produced more errors than any of the other 3 procedures. However, if TTC is coupled with progressive prompt delays, it can be as effective as FC.

In one of the first systematic studies of the three procedures, Walls, Zane, and Ellis (1981) required vocational rehabilitation clients (mildly to moderately retarded) to complete three complex assemblies (carburetor, bicycle brake, and meat grinder). Using random assignment of participants to conditions, and counterbalancing the order of presentation and assemblies, Walls et al. had each participant learn by a different method on each of three consecutive days. Instruction and physical prompting were used in the training trials to facilitate learning new steps in each component of the chain. A measure of the proportion of errors indicated FC and BC were similar, while TTC resulted in a higher proportion or errors. However, a problem here is that the number of responses was not equal -- FC and BC had a similar number of responses which had to be emitted to complete the task, but TTC had fewer responses required for completion. It might be the case that if the TTC procedure allowed for more responses, then the proportionate number of errors might be lower in that condition (i.e., at least equal to the other two procedures). However, those participants who required the greatest number of trials in the TTC method were also found to be responsible for the greatest number of errors in the TTC method. Walls et al. suggest that lower-functioning individuals (moderately retarded) may make more errors with the TTC methods, than with the FC and BC procedures. However, the research by Ash and Holding (1990) mentioned earlier suggests that this finding also occurs in the undergraduate student population.

The Present Study

Spooner and Spooner's (1984) review of chaining procedures in studies using mentally challenged individuals suggested that the results are mixed on the relative effectiveness of the chaining procedures outlined above. If both effectiveness and efficiency are reasonable criteria on which to base a learning outcome, then we need to examine which dependent variables measure these criteria (e.g., time to completion of chain, number of correct and incorrect responses, and trials to criteria). The number of trials does not necessarily have a time stipulation -- trials can take any amount of time to complete --so unless researchers control for this variable, it is difficult to assess the contribution that information about the number of trials makes to the body of knowledge about chaining procedure effectiveness. Also, fluency of performance (i.e., the ease, or speed, with which one performs the sequence of responses), rather than simple accuracy measures, might better indicate whether the newly acquired skill is maintained and generalized. Spooner and Spooner also suggest that the rate at which correct responding accelerates, and error frequency decelerates, is an indicator of learning. Further, rate of responding is a good indicator of future learning.

As mentioned, there has been no clear study of the relative effectiveness of all three main chaining procedures (FC, BC and TTC) while holding precisely specified, controlled shaping parameters constant. The present research contributes to the body of knowledge in shaping and chaining areas, but more specifically to the area of chaining effectiveness. In order to carry out a systematic study of chaining, the present study employed methods that were effective in previous research. A modification of the video - tracking system used previously (Pear & Legris, 1987; Pear et al., 1996) was used to determine if this system is effective in training a chain of arm movements. The study assessed the relative effectiveness of FC, BC, and TTC procedures, while holding the shaping parameters (FSS and BSR) for establishing the responses making up the chain constant.

Rationale for Approach

There are a number of questions about methodology that may be raised. First, why did I adopt a behavior analytic approach to this problem rather than an inferential - statistical approach? The main reason for this is based upon the premise that we may be able to eventually discover some general laws of behavior. In order to ascertain whether a general law exists, we must establish that an effect on an independent variable is present for each participant in a study. While it may be interesting to determine what is true for one group of individuals relative to another group, such an approach does not guarantee replicability across individuals. For instance, if we find that on the average, FC and BC are more effective in terms of target response rate and number of trials completed than TTC, there is no guarantee that this is true for everyone. If, in contrast, we find that this is true for every individual in a relatively small sample, there is a good chance that it will be true for virtually all individuals who fit the specifications of the sample.

Two further questions arise from the above: (a) Why not use a large number of participants and (b) Why use a between groups design? Sidman (1960) suggests:

> As a criterion of reliability and generality, intersubject replication is a more powerful tool than intergroup replication. Intergroup replication provides an

> indicator of reliability insofar as it demonstrates that changes in the central tendency for a group can be repeated. With respect to generality, however, intergroup replication does not answer the question of how many individuals the data actually represent. With intersubject replication, on the other hand, each additional experiment increases the representativeness of the findings. Indeed, replication of an experiment with two subjects establishes greater generality for the data among the individuals of a population than does replication with two groups whose individual data have been combined. (p. 75)

Thus, when an experiment is replicated across individuals, we can feel fairly confident that there is a systematic finding that generalizes across these individuals. To answer the question of how many participants one should use in an experiment, I appeal to my own previous work and that of others in the area of study. As Sidman suggests, my individual judgment is not analogous to a "whim"; rather, it is based upon accepted methodology within the field. In reviewing the behavioral literature in the Introduction, the number of participants in all of the studies ranges from 1 - 22, with the median (most reflective of central tendency in this population) at n = 4. There is a bimodal characteristic to the population of studies: n = 1 and n = 4 both represent the mode of sample size in the literature. Thus, an n = 4 for each comparison within the current study is consistent with the research carried out in the literature and in our laboratory.

A further point that Sidman (1960) makes is that even if there is an error (i.e., if my findings are not replicated in later research), then at least the essence of science is that it is self-corrective. The applies also to inferential-statistical designs, which assess the differences that exist in central tendencies for various groups. The difference is that I am interested in what is true for individuals, which should generalize to the group level. An inferential - statistical approach cannot guarantee that what is generally true for a population is also true for each individual within that population. Likewise, extrapolating to an entire population from a smaller sample size may not be wise, but over time evidence from the data will either support or correct the earlier findings.

Another question is: Why split the comparisons among three groups of individuals? Why not simply run all three conditions for all participants? The reason for this is that in the past, when I have placed participants in one study under more than two comparisons, the results have indicated that there is considerable interference between the conditions. I have observed much clearer differences when testing only two levels of the independent variable on each participant.

Based upon previous research in both areas, I predicted the following. First, the modified computer algorithm would successfully shape limb movement toward all of the targets contained in the fixed sequence trained. Second, the algorithm would be successful in facilitating training using FC, BC, and TTC procedures. Third, I anticipated that the training time will be shorter in the TTC condition, than in the FC and BC procedures.

Method

Participants

Twelve participants (8 men and 4 women, mean age = 21.1 years) were recruited, for two sessions of one hour each, from Introductory Psychology courses at the University of Manitoba in partial fulfillment of their course requirements. At time of recruitment, potential participants were told that the experiment involved moving their right arm around in a defined area to find invisible targets.

Apparatus

An experimental room (3.66 x 7.93 m) on the main floor of the Duff Roblin Building was used to carry out all sessions and to collect data. A black drape hanging from the ceiling in front of the participant's chair acted as a barrier to prevent all but the right arm from entering the "virtual chamber". The virtual chamber was a rectangular area defined by the program for each participant by the measured length of his or her arm, and was the three-dimensional space in which limb movement was tracked. Two Panasonic WV-B1200 video cameras, parallel to one side of the area defined as the virtual chamber, were attached to an IBM-compatible personal computer equipped with a VGA monitor. An XT computer was "slaved" to the IBM compatible computer, and used to display discriminative stimuli for each target location. A computer program developed to track objects in three-dimensional space was used to collect information from the cameras, calculate data points, command the slaved computer output, and deliver reinforcement. Three different tones emitted by the computer acted as: (a) a shaping sphere reinforcer, (b) a target hit reinforcer, and (c) an end of component reinforcer. The XT computer (facing the participant) displayed Arabic numerals 1, 2, and 3 to act as discriminative stimuli for the relevant target.

Two video acquisition (VA) cards in the computer, connected to the cameras, received the camera images of the defined cubic space, and scanned the image from left to right and top to bottom until a contrasting white spot (a mitt covering the hand) was located relative to a black background. The process occurred 60 times per second, while the resolution was averaged for every sixth response, thereby recording 10 samples per second. Averaging in this manner increased the stability of the image, and reduced what would otherwise be an overwhelming amount of data. The VA cards stored the Cartesian coordinates of the highest point of a white object on a black background in three - dimensional space in a First - In First - Out (FIFO) buffer located in memory on the cards. This buffer ensured that data would not be lost when the computer was busy with other processes (e.g., emitting a tone and/or controlling the slide projector).

The VA cards recorded the most recent coordinates of the white object, relative to the targets selected by the computer. This information was then processed by a shaping - chaining program which performs all the computer-related actions already described. In addition, a shaping sphere operated by the program was concentric to the target currently in effect, and reacted accordingly to the FSS and BSR parameters. The program stored time of image, coordinates of the white spot and targets, distance from targets, time and duration of reinforcements. All data were saved to disk at the end of the session. Real-time data were used to: (a) control the radius of the shaping sphere, (b) determine if reinforcement criteria was met, (c) present discriminative stimuli, and (d) present reinforcement.

Black felt cloth attached to the walls surrounding the tracking area rendered all of the virtual chamber totally black. A sleeve made from black polyester/cotton fabric with adjustable wrist and shoulder drawstring closures covered the participants' right arm. A shoulder cover made from the black polyester/cotton fabric served to cover clothing from the neck to the shoulder drawstring. A white spandex thumbless mitt constructed with an elastic wristband covered the participant's right hand.

Procedure

Each participant served in two 1-hour sessions. The experimenter met the participant in a special waiting room, and escorted him or her to the experimental room. Once there, the experimenter demonstrated a number of stretching exercises concentrated on the neck and shoulder muscles, and requested that the participant warm up prior to starting the experiment. The participant was then seated to the left of the area of the virtual chamber. A measurement (in mm) taken of the participant's arm (up to the knuckles) was entered into the shaping-chaining program, and the area comprising the virtual chamber was calculated by the computer program. The experimenter then requested that the participant put the experimental black sleeve and white mitt on over his or her own clothes. The experimenter then draped black material cover over the participant's right shoulder such that the entire right side from the neck to the wrist was covered in the black material. Next, the experimenter asked the participant to read the instructions (see Appendix B). The instructions were the same for all three conditions. In general, participants were told that there were a number of invisible targets to be located in a particular order. A tone indicated they were getting closer to a target, and did not sound as they moved farther away. A different, higher, tone sounded upon contact with each target. A third tone (lower in pitch than the other two) sounded upon completion of each component of the trial, and resulted in a point recorded as well. Participants were asked to continue trying to locate the targets in the correct order until they earned 8 points or I asked them to stop, whichever occurred first. Participants were also informed that they could rest their arm on the table at any point during the session, as long as they did not remove the hand from the metal cube. This instruction was included verbally in order to cut down on tracking losses. Prior to beginning the session, I asked if the participant had any questions about the procedure. As questions arose, I answered by simply repeating or paraphrasing the instructions already provided to maintain uniformity of treatment over participants. During two sessions for one participant, a second experimenter was present to observe the procedure.

The research design was an Individual Organism A-B-A-B-A-B design. Participants were randomly assigned to one of three combinations of the three conditions (FC, BC, and TTC) until each combination had a total of four participants. Each participant was exposed to the same two alternating treatments throughout sessions. Thus, the twelve participants recruited for the study were randomly placed into one of the three conditions (see Table 1).

To control for order effects, each participant in a condition received the two chaining procedures in a different order. For instance, in Condition A, two participants were exposed first to FC and then to BC. For the entire session, the two procedures alternated strictly. The other two participants in that condition received alternating treatments of BC followed by FC. Each condition was counter-balanced in this manner.

Table 1

Condition Name, Chaining Procedure, and Number of Participants in Study

Condition Name	Chaining Conditions in Procedure	Number of Participants
Condition A	Forward Chaining Backward Chaining	4 (2 in each order)
Condition B	Forward Chaining Total Task Chaining	4 (2 in each order)
Condition C	Total Task Chaining Backward Chaining	4 (2 in each order)

Table 2

Components in Training and Test Phases by Procedure and Total Points Earned

Procedure	**Components in Training Phase (T = Target)**	**Training Points Earned**	**Number of Test Phases**	**Total Points Earned**
Backward Chaining	(a) T3 (b) T2 -> T3 (c) T1->T2->T3	3	5	8
Forward Chaining	(a) T1 (b) T1->T2 (c) T1->T2->T3	3	5	8
Total Task Chaining	(a) T1->T2->T3 repeated 3 times	3	5	8

Within each one hour session, a number of trials took place. A trial ended when a specified criterion was reached, or when 5 minutes had elapsed. The criterion was based on the number of points earned, and was determined as follows. In the BC and FC procedures, the recursive nature of the training session resulted in 3 points earned during training (see Table 2). The subsequent testing phase to test whether the participant has learned the sequence resulted in 5 additional points, for a total of 8 points per trial. Since TTC only results in reinforcement contingent upon the completion of the entire chain, training using the TTC method was carried out 3 times in order that the amount of reinforcement for completing the chain would be the same for all chaining procedures.

To control for fatigue effects within each trial, participants could rest or stretch at any point during a session. If they did so during a given trial, then they were asked to keep their arms within the metal cube to prevent loss of camera tracking. To prevent strain, stretching (demonstrated earlier in the session) was encouraged by the experimenter during rest breaks, time between trials, and at beginning and end of each session.

Shaping Procedure

Shaping was used throughout the chaining procedures to train the location of 3 targets, each with a 60 mm radius, and 200 mm apart from each other. The recorded x, y, z coordinates of each target defined the location of the shaping sphere around a given target. Each target had a shaping sphere, but it was only activated when that target was selected as the next one to be trained or reestablished during the training and phases. Before a given target had been contacted, its shaping sphere expanded to the current location of the white-mitted hand and contracted according to an FSS criterion of 5 mm to successively change the criterion for reinforcement (see Figure 1 for a flowchart of the

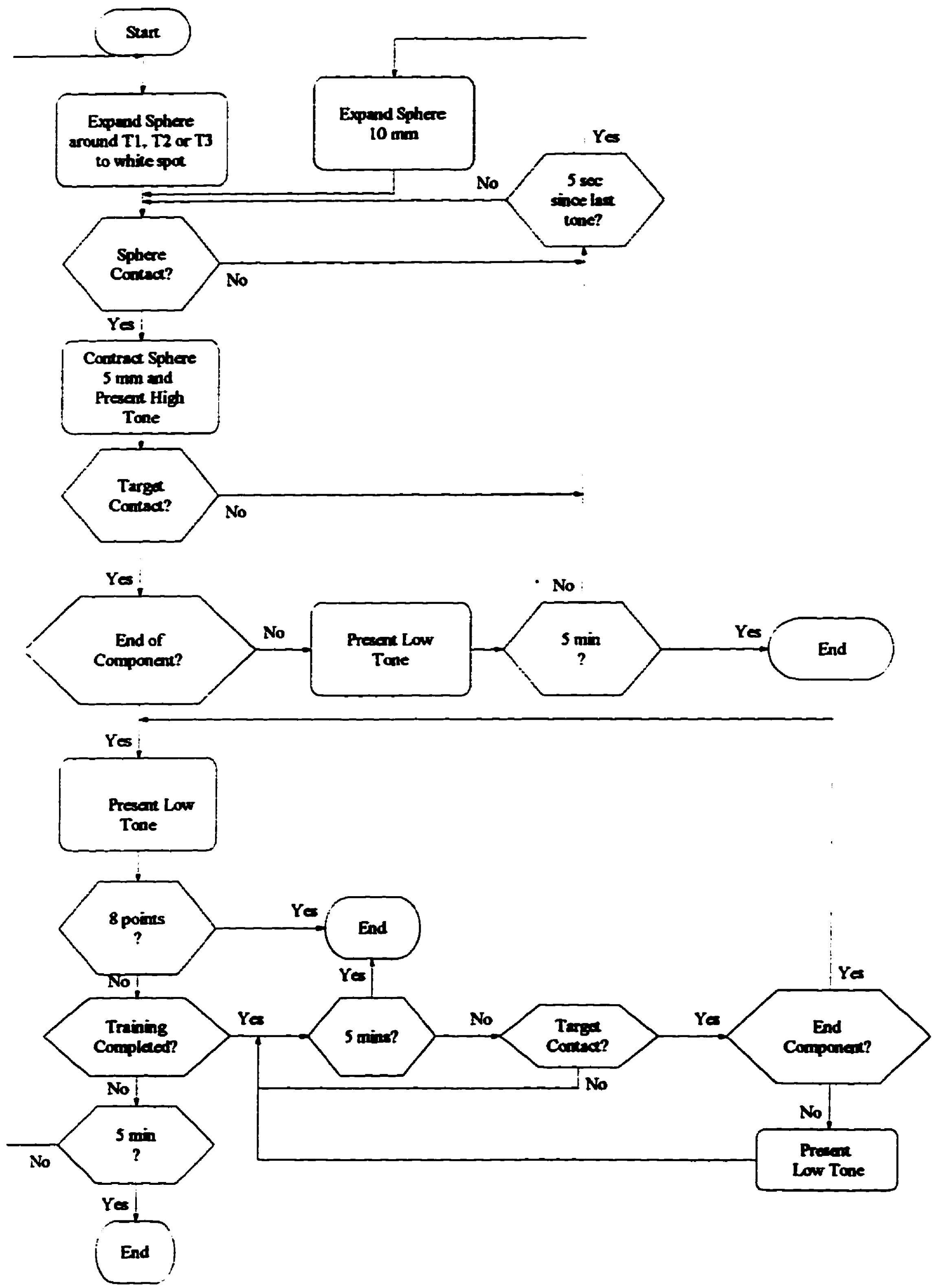

Figure 1. Flowchart of the computer algorithm used to shape and chain a sequence of responses.

algorithmic decisions). On subsequent training with a given target, the shaping sphere radius was initially equal to the target radius. A tone was emitted by the computer to reinforce contact with the shaping sphere. The backstep size was set at 10 mm, and operated for the active target throughout training, after a period of 5 seconds in which reinforcement did not occur (BSR = 10 mm/5s). In this manner, FSS and BSR parameters found to be effective in work by Pear et al. (1996) and Crone-Todd and Pear (1996) were used to shape the topography of movement toward the target(s) location.

Chaining Procedure

Chaining the sequence in which the targets were located for each of the three conditions occurred as follows (see Table 2 and Figure 1).

Forward chaining procedure. Once the first target was contacted, a tone different from that used in the shaping-to-target procedure was emitted by the computer. The shaping sphere remained in effect around Target 1 (T1), according to the FSS and BSR values specified in the shaping procedure above, until a second contact with the target was made. Upon the second contact, the T1 shaping sphere no longer operated, and the Target 2 (T2) shaping sphere was activated. After contact with T2 occurred, the T1 shaping sphere was again activated (i.e., with its initial radius equal to the target radius). Contingent upon contact with T1, the T2 shaping sphere activated again. Once T2 was contacted, the Target 3 (T3) shaping sphere activated. Thus, the procedure was outlined as follows:

Shape to T1 (tone +1 point) ⇒ Shape to T1 (tone) -> Shape to T2 (tone + 1 point ⇒ Shape to T1 (tone) -> Shape to T2(tone) -> Shape to T3(tone + 1 point)

In each component of the chaining procedure, a tone different from that used in the shaping procedure was presented for each target contact. The tone that was contingent on target contact provided reinforcement for locating each target within the sequence, until the current component was completed.

Backward chaining procedure. This procedure was basically identical to the above procedure, except carried out in the reverse order. Thus, the procedure was as follows:

Shape to T3 (tone + 1 point) ⇒ Shape to T2 (tone) -> Shape to T3 (tone + 1 point) ⇒ Shape to T1(tone) -> Shape to T2(tone) -> Shape to T3(tone + 1 point)

Total task chaining procedure. As mentioned previously, the TTC training procedure involves presenting the total sequence of targets to the participant three times in a row. During the training phase, the shaping sphere operates around the currently active target. Thus, the procedure is outlined as follows:

Shape to T1 (tone) -> Shape to T2 (tone) -> Shape to T3 (tone + 1 point)

Note that the procedure as outlined is identical to the final component in each of the other two procedures.

Test Phase

The test phase required that the sequence as trained in the final component of each training procedure be repeated five times. For each repetition of the sequence, the lowest tone was emitted to indicate that another point has been earned. As mentioned previously, the trial ends contingent upon the test phase criterion, or when 5 min have elapsed since the beginning of the trial.

The sphere remained inactive during the test phase, and reinforcement was contingent only on target contacts and completed three-target sequences.

Measures of Interest

The measures of interest concern the effectiveness of the procedure in place. Thus, dependent measures include: (a) the mean number of completed training and test sequences in a given procedure, (b) the mean time per target hit in training and test phases per trial by procedure by participant, and (c) mean change in target hit rate from training to test phase.

The mean number of completed training and test sequences indicated whether or not a particular procedure results in more often completing both of these phases. For instance, if TTC is more effective in training the sequence than BC or FC, than we might expect a person to reach criterion quicker in a TTC session than in BC or FC. The mean time per target hit measures the amount of time it takes, on average, for participants to locate each target in both phases. The mean change in target hit rates indicates whether performance changes from the training phase to the test phase. Representative graphs of movement for the three comparisons are included to demonstrate the topographical change in movement between the targets. Finally, representative graphs of the distance from each activated and non-activated target, over time, indicates how systematically representative participants move toward the next target in the sequence. Analysis of this graph assesses whether a particular procedure might be more likely to result in moving to a different target than the one defined by the computer as next in the sequence. The distance - over - time graphical analysis also reveals systematic movements (errors) toward a target not currently defined as "next in the chain".

During data collection, there were a few occasions on which the hard drive ran out of space. Therefore some of the data was lost for each of six participants.

Results[2]

Summary Information

Backward Versus Forward Chaining. Figure 2 shows the average amount of time spent in training and test phases for both conditions across all four participants. Notice that there is no consistent difference between BC and FC training time (i.e., there is no clear advantage in training time for one condition over the other), but that there is a consistent difference in the amount of BC and FC test time: Less time is generally spent in testing during BC sequences than in FC sequences for all four participants.

Figure 3 displays the average amount of time between target hits in both FC and BC conditions. Note that there were consistently more rapid target hits in the BC condition relative to the FC condition during training. This suggests that there was more rapid learning of the target positions in the BC condition than in the FC condition. As such, it might not be surprising that the amount of time spent in the test phase (Figure 2) is lower in BC. That is, more rapid target position learning may have resulted in faster replication of the sequence in the test phase.

[2] Appendix C contains the recorded summary data from each participant in each condition for each trial over both sessions. Included in the summary are the trial numbers for which data was lost in saving to a full disk.

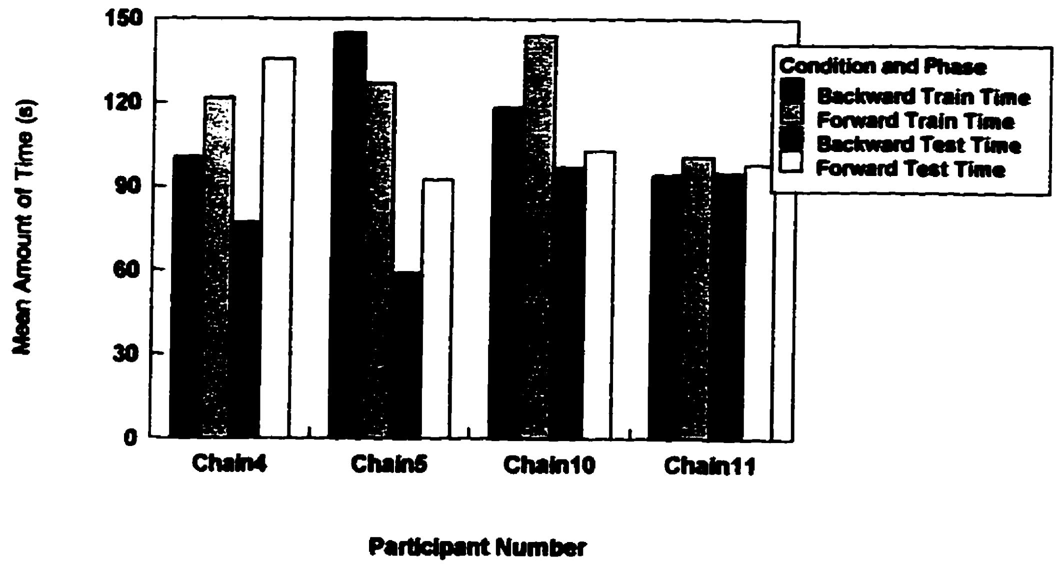

Figure 2. Mean amount of time in training and test phases for each participant in the FC - BC comparison.

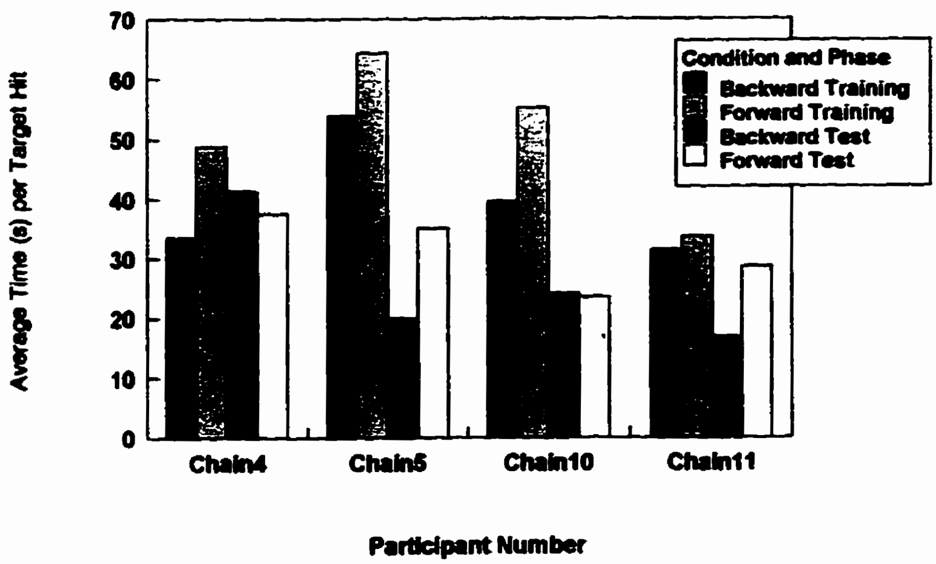

Figure 3. Mean time between target hits for entire session for BC and FC procedures for each participant.

Figure 4 shows that three of the participants increased target response rate in the test phase in both conditions. With the exception of Chain4, whose data indicates a decrease in speed during the test phase, most participants were able to locate the targets again more rapidly than in the training session.

Figure 5 indicates that the Training Phase was completed at least as often, or more often, in the BC condition than in the FC condition. This relationship also occurs when comparing the percentage of completed trials in both conditions. Thus, it appears that BC generally produces faster (or equal) target hits during the training phase, time to test the sequence, and completed training and test phases.

<u>Forward Versus Total Task Chaining</u>. Since the total number of targets to be hit in the training phase was higher in TTC condition (9 target hits as compared to 6 in both FC and BC conditions), a measure of the average amount of time spent in training and test phases is not a fair one to consider: If the target response rates were the same, then the training phase during TTC would automatically take longer to complete. Alternatively, if TTC actually produced faster response rates, then the time to complete the training phase could obscure this finding. Thus, for in the comparisons of BC versus TTC (and FC versus TTC in the next section), the measures of interest center on the average time per target in both phases, average change in target response rate from training to test phases, and the percentage of completed training and test phases, all by condition.

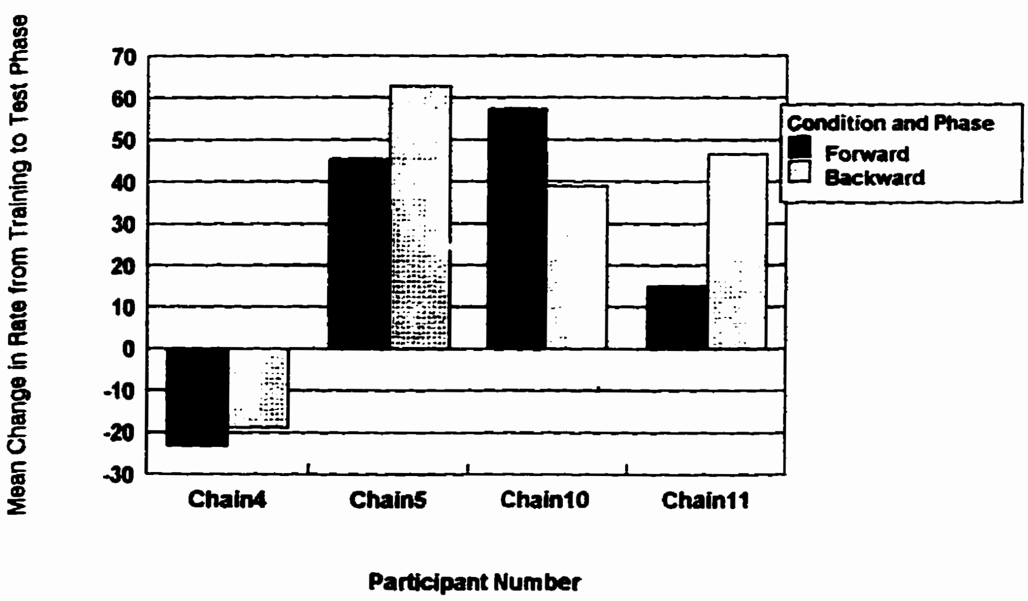

Figure 4. Mean change in target response rate from training to test phases between BC and FC procedures, for each participant participant.

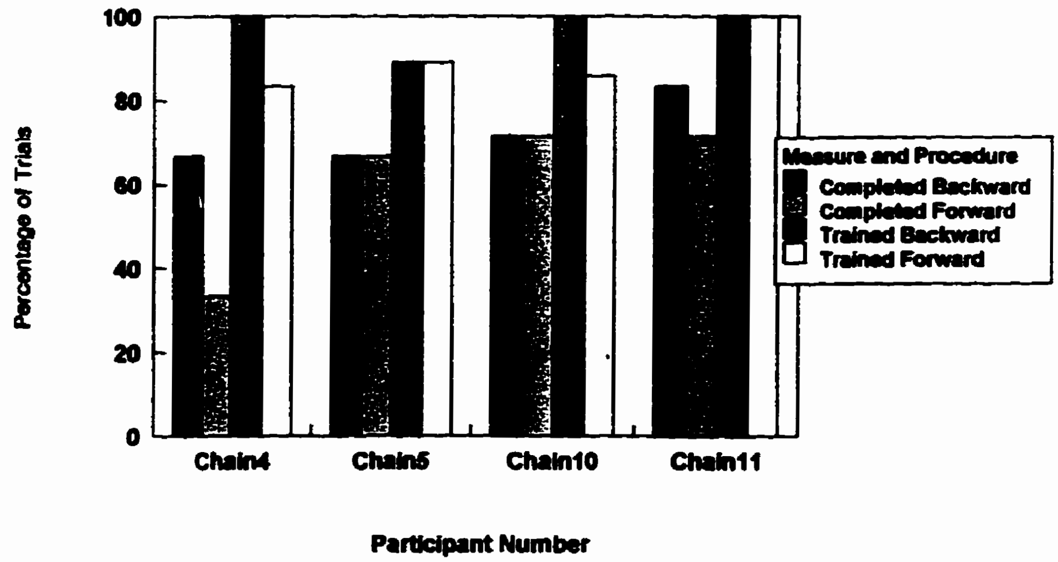

Figure 5. Percentage of trials, for BC and FC procedures, in which training and testing phases were completed, for each participant.

Figure 6 shows that FC always resulted in a shorter mean time per target hit in training, as compared to TTC. However, there is no systematic difference present on this measure during the test phase.

Figure 7 shows that in all cases, the mean change in target hit rate from training to test phase rate increased during TTC phases. For two participants, the rate per target hit decreased during the FC test phase. Figure 8 indicates that the percentage of completed FC training and test phases was equal to, or greater than, those in TTC.

Taken together, these measures suggest that the FC procedure resulted in a more rapid training target hit rate than the TTC procedure, and that for 3 of the 4 participants, the greatest reduction in target hit rates occurred in the TTC condition. It is difficult to determine whether the greater change in target hit rate between training and test phases in TTC is due to the effects of learning during training. An alternative explanation could be that since the training phase produced a shorter target hit time in FC, that this measure was more free to vary in the TTC condition. That is, since there was more "room" to improve on the target response rate in the TTC condition, then the data were more likely to find a greater improvement in same. What this does show is that learning occurred in the TTC condition despite slower target response rates during training.

Backward Versus Total Task Chaining. Figure 9 indicates no systematic difference between the average target hit time in BC and in TTC. However, BC target hits occurred more rapidly for all four participants in the BC condition than in the TTC condition.

Figure 10 shows that in all cases, the rate of target hit responses increased in test phases for both conditions. Recall that in the previous comparison groups, that in some cases this rate decreased. For 3 or the 4 participants, TTC resulted in a greater rate

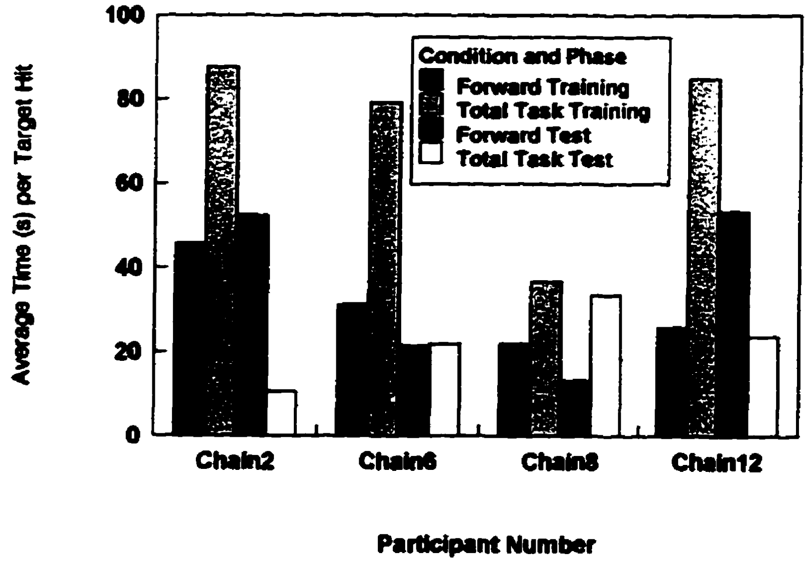

Figure 6. Mean time between target hits for entire session for FC and TTC procedures for each participant.

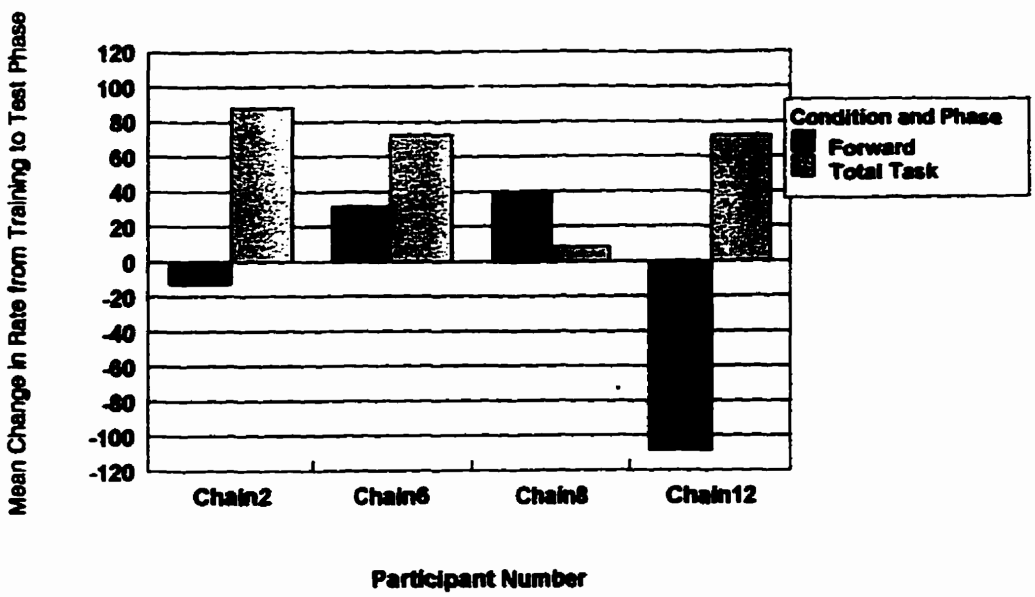

Figure 7. Mean change in target response rate from training to test phases between FC and TTC procedures, for each participant.

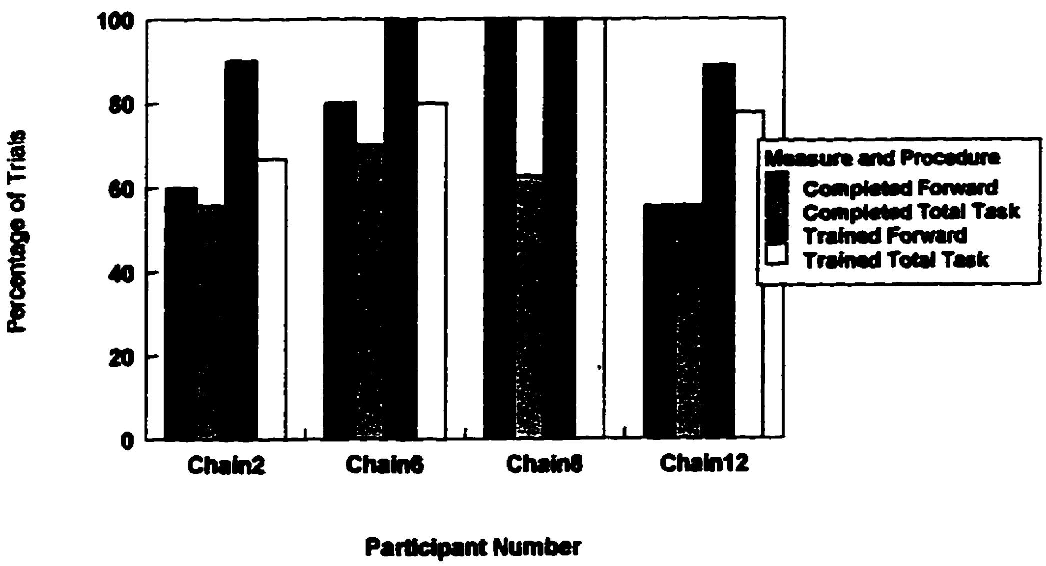

Figure 8. Percentage of trials, for FC and TTC procedures, in which training and testing phases were completed, for each participant.

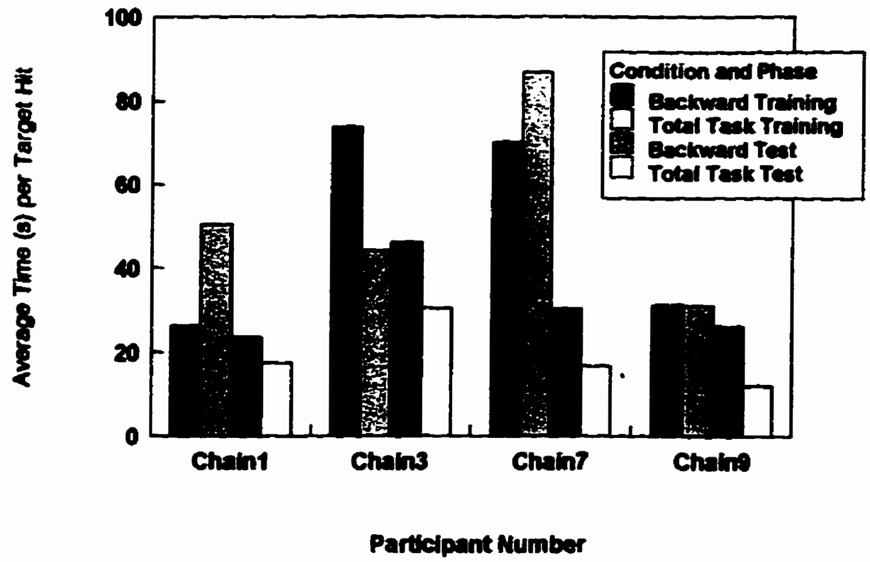

Figure 9. Mean time between target hits for entire session for BC and TTC procedures for each participant.

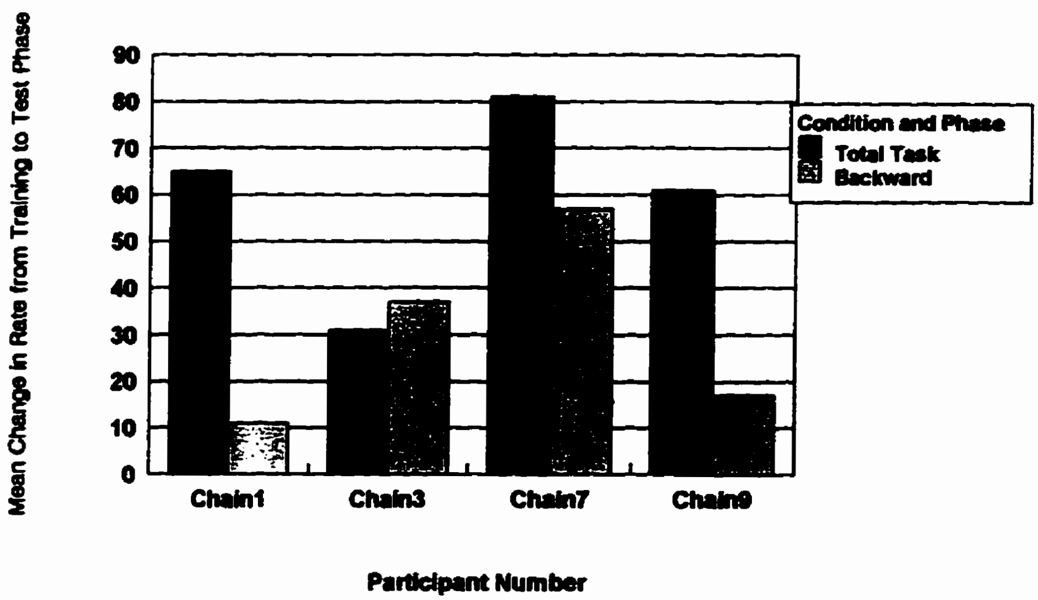

Figure 10. Mean change in target response rate from training to test phases between BC and TTC procedures, for each participant.

change. Again, this could mean that rates produced by TTC were more free to vary than those under BC.

Figure 11 indicates no systematic difference in the percentage of completed trials in BC and TTC procedures. However, the number of completed BC training phases is equal to, or greater than, that in the TTC condition.

General Patterns of Responding

Figures 12 through 17 are representative graphs of the distance from each target over trial time for one participant from each comparison condition. Event line a records the amount of time reinforced for contact with the shaping sphere, and event line b indicates when a reinforcer occurs for target contact. Generally movement toward the selected target increased upon reinforcement. Further, when no reinforcement occurs, movement became a bit more variable. Notice that during the test phase (event line d), the movement toward the target became less variable than in the training phase. The movement variability decreased to around 200 - 250 mm away from a given target. Since the targets are all 200 mm apart, we could expect as a minimum this kind of variation in movement between the three targets during this phase.

The target most often not located in test phases was Target 2 (see Fig. 12, 13, and 15). Interestingly, some trials in FC and BC indicated that the less-repeated targets were more often more difficult to relocate. That is, in the FC condition, target 3 at times took longer to relocate during testing (see Fig. 14), while in the BC condition, target 1 took longer (see Fig. 16), relative to the other two targets.

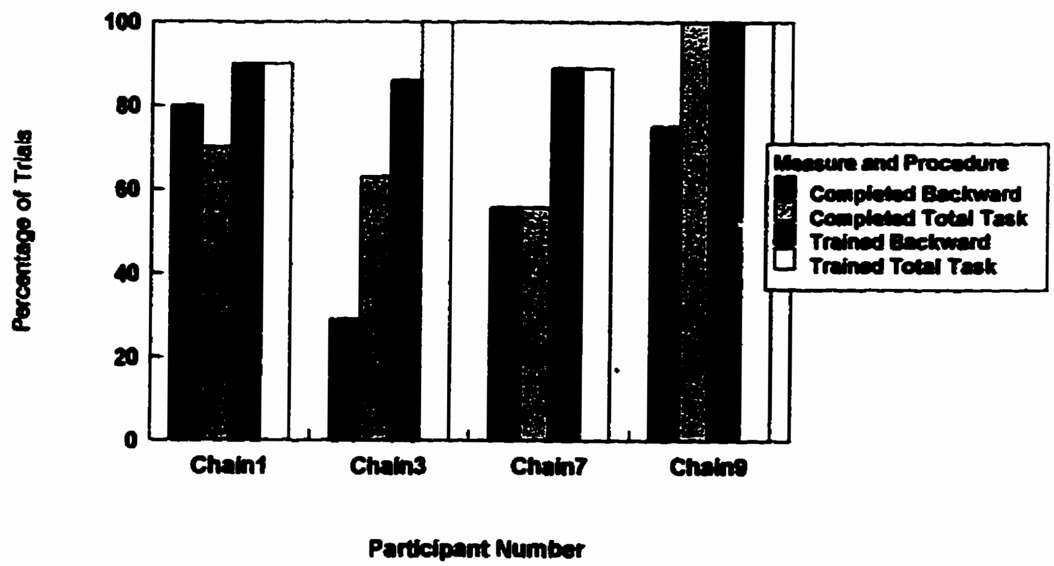

Figure 11. Percentage of trials, for BC and TTC procedures, in which training and testing phases were completed, for each participant.

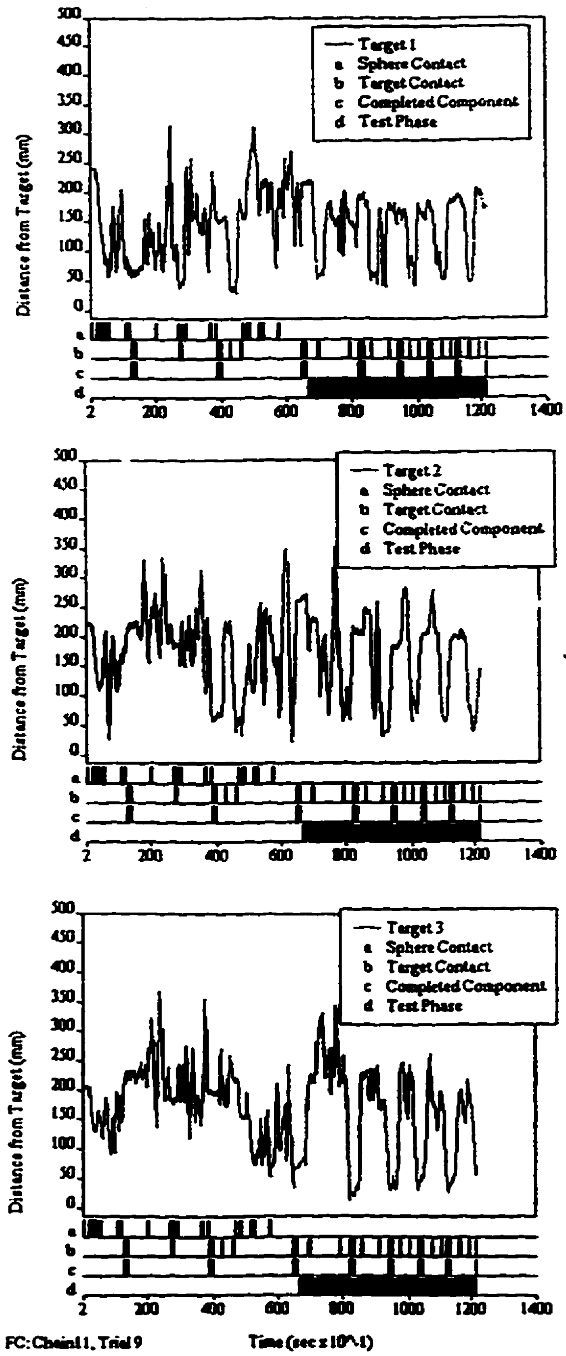

Figure 12. Distance from target measures for all three targets in FC for Participant Chain 11 in trial 9. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

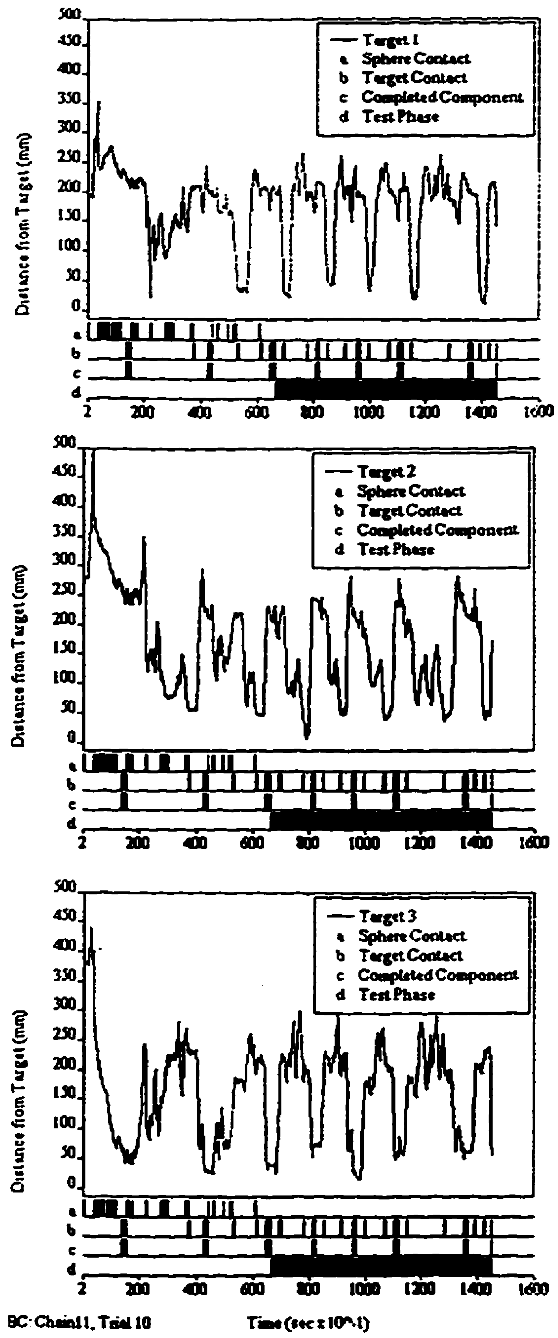

Figure 13. Distance from target measures for all three targets in BC for Participant Chain11 in trial 10. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

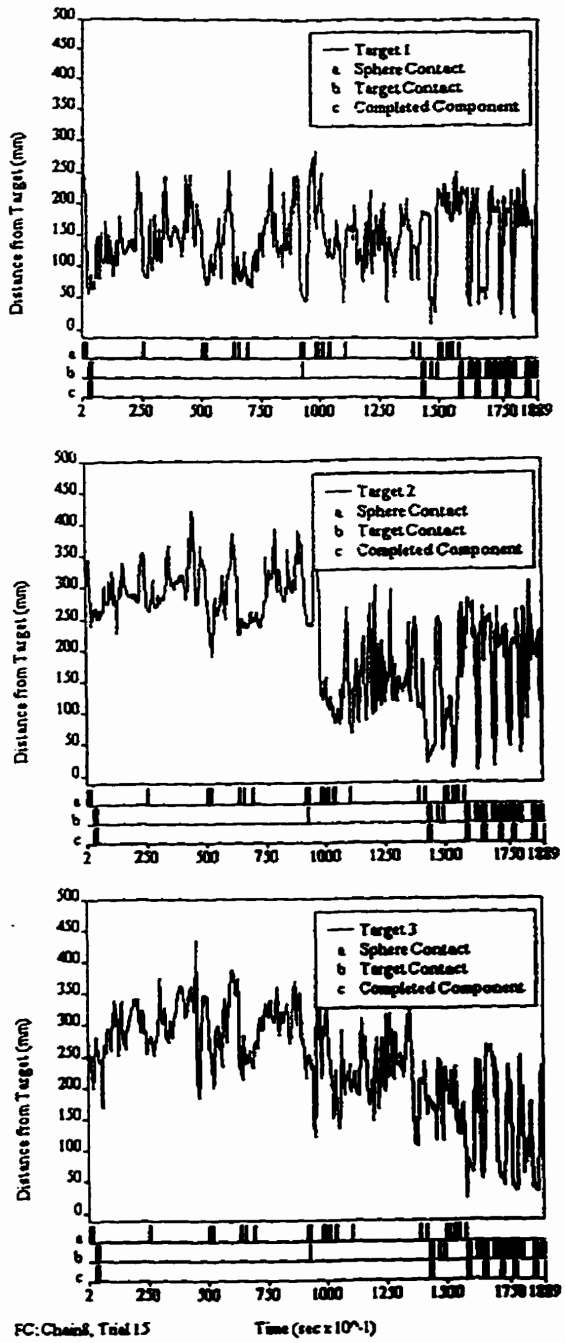

Figure 14. Distance from target measures for all three targets in FC for Participant Chain8 in trial 15. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

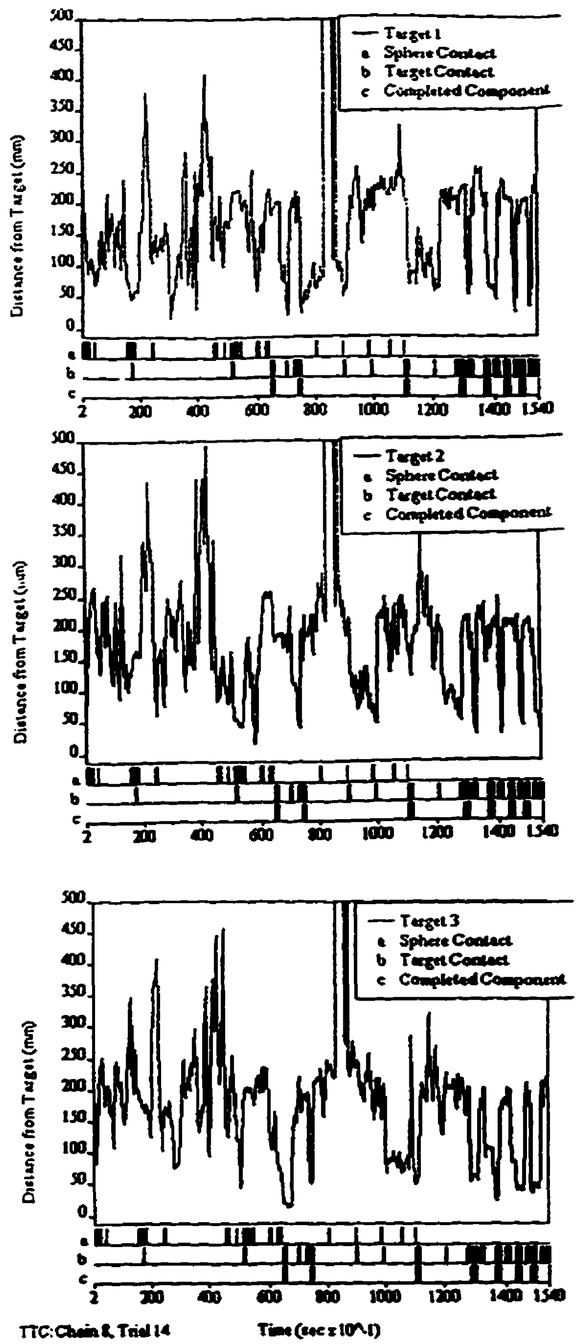

Figure 15. Distance from target measures for all three targets in TTC for Participant Chain8 in trial 14. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

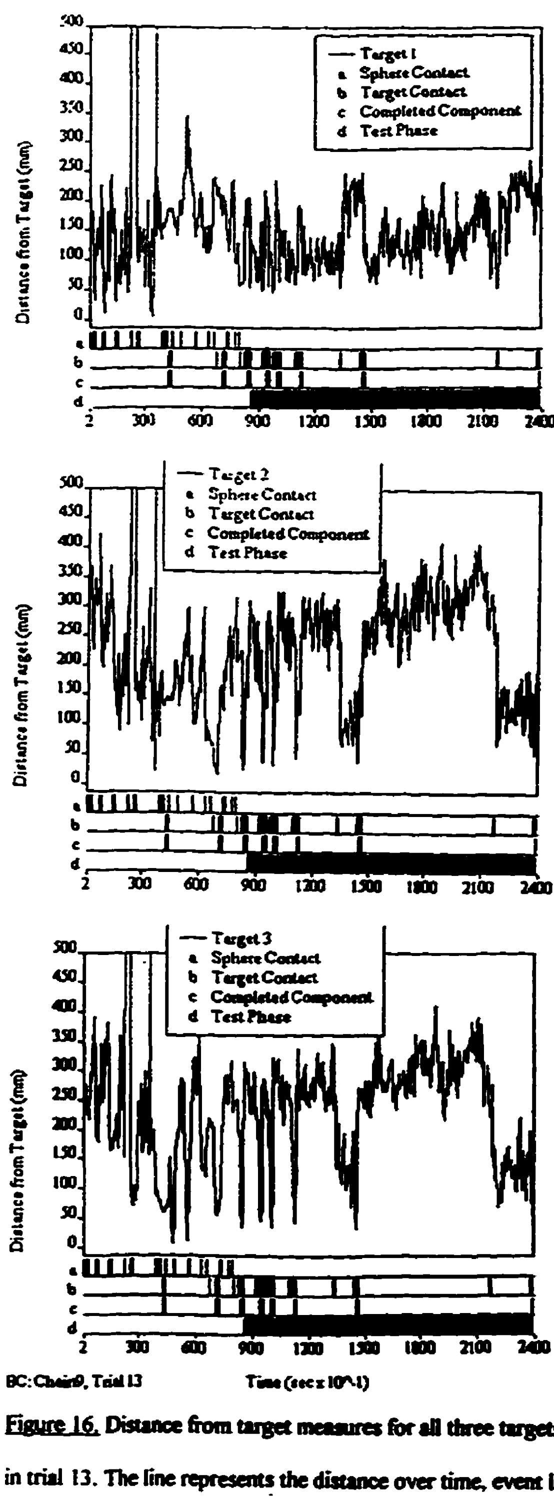

Figure 16. Distance from target measures for all three targets in BC for Participant Chain9 in trial 13. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

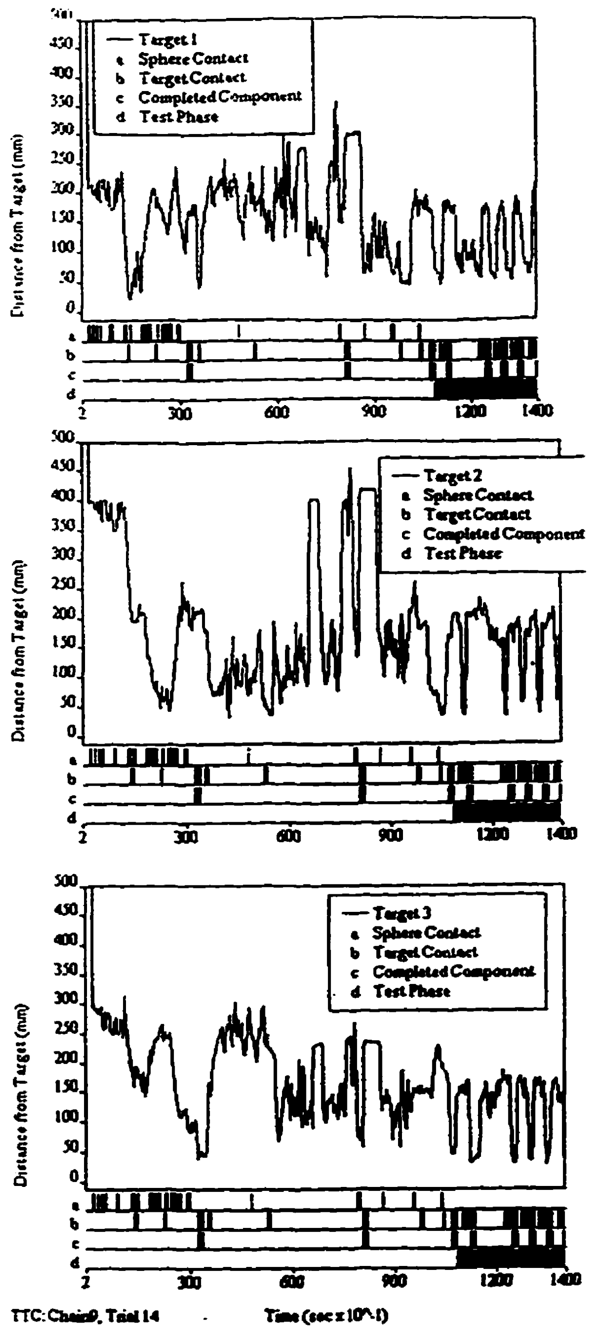

Figure 17. Distance from target measures for all three targets in FC for Participant Chain9 in trial 14. The line represents the distance over time, event line a represents duration of reinforcement for shaping sphere contact, event line b represents target hit reinforcement duration, event line c completed component reinforcement, and event line d indicates duration of testing phase.

<u>Other Patterns of Responding</u>

Generally, the pattern of responding appears to have taken on the shape of a circle or triangle by the time of the test phases. Figure 18 is a representative sample (Chain11), which covers 1 second periods starting at 67 seconds. Notice how after a Target 3 hit, the movement is to Target 1, then to Target 2, and back to Target 3, all in succession (Target 2 is directly behind Target 3 in this sample). This was the predicted pattern of movement between the three targets.

An interesting artifact of reinforcement is that sometimes behavior is reinforced that one did not originally plan on. For instance, Chain1 and Chain10 both engaged in regular hand resting in between target hits. In Figure 19, we see cumulative 1 - second time slices for Chain1 (starting at time 38 sec.). Notice how movement begins at the bottom of the cube, moves up to Target 1, then down again, up to Target 2, back down, and then up to Target 3. For Chain1, this movement pattern begin during the fifth trial, which was the first trial in which he completed all components. Thus, it appears that since this strategy was effective during this trial, and continued to be for the rest of the trials, that he was more likely to use it again. At the completion of both trials, Chain10 indicated that he had used the handresting as a way to orient between the targets, while Chain1 indicated that he had used it only for resting purposes. However, Chain1's responding indicated that he had likely undergone similar contingencies. Thus, I infer that Chain1's handresting responses had been reinforced, despite his verbal report otherwise.

Figure 20 displays what may be another method of orienting between the three targets. Chain12 repeatedly used what I will refer to as an "L-shaped" movement, in which Target 2 was always covered between targets 1 and 3. Notice how the initial movement

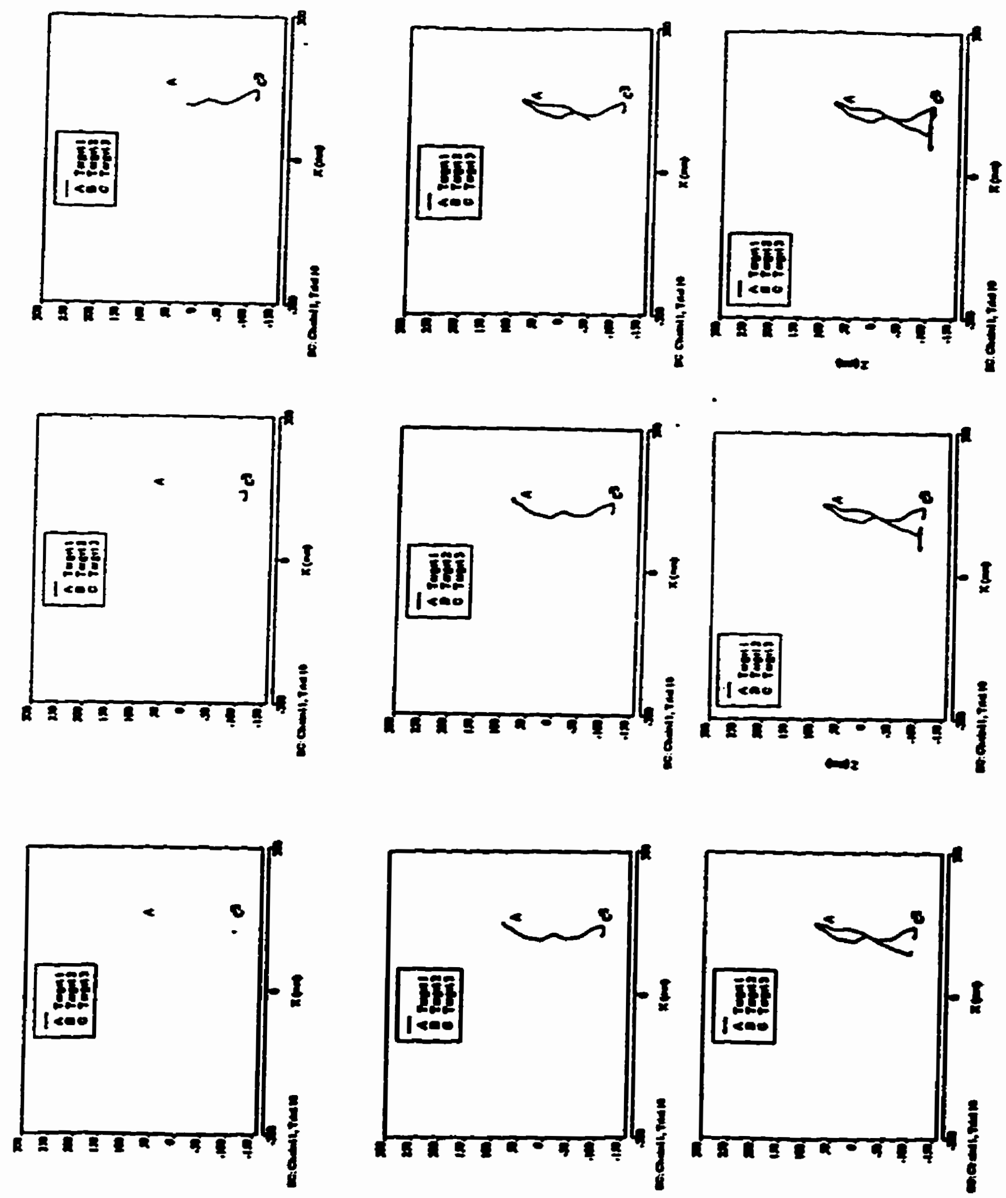

Figure 18. Cumulative x-z coordinate 1 sec frames of responding by Chain11 in test phase of trial 10, under BC procedure. A represents target 1, B represents target 2, and C represents target 3.

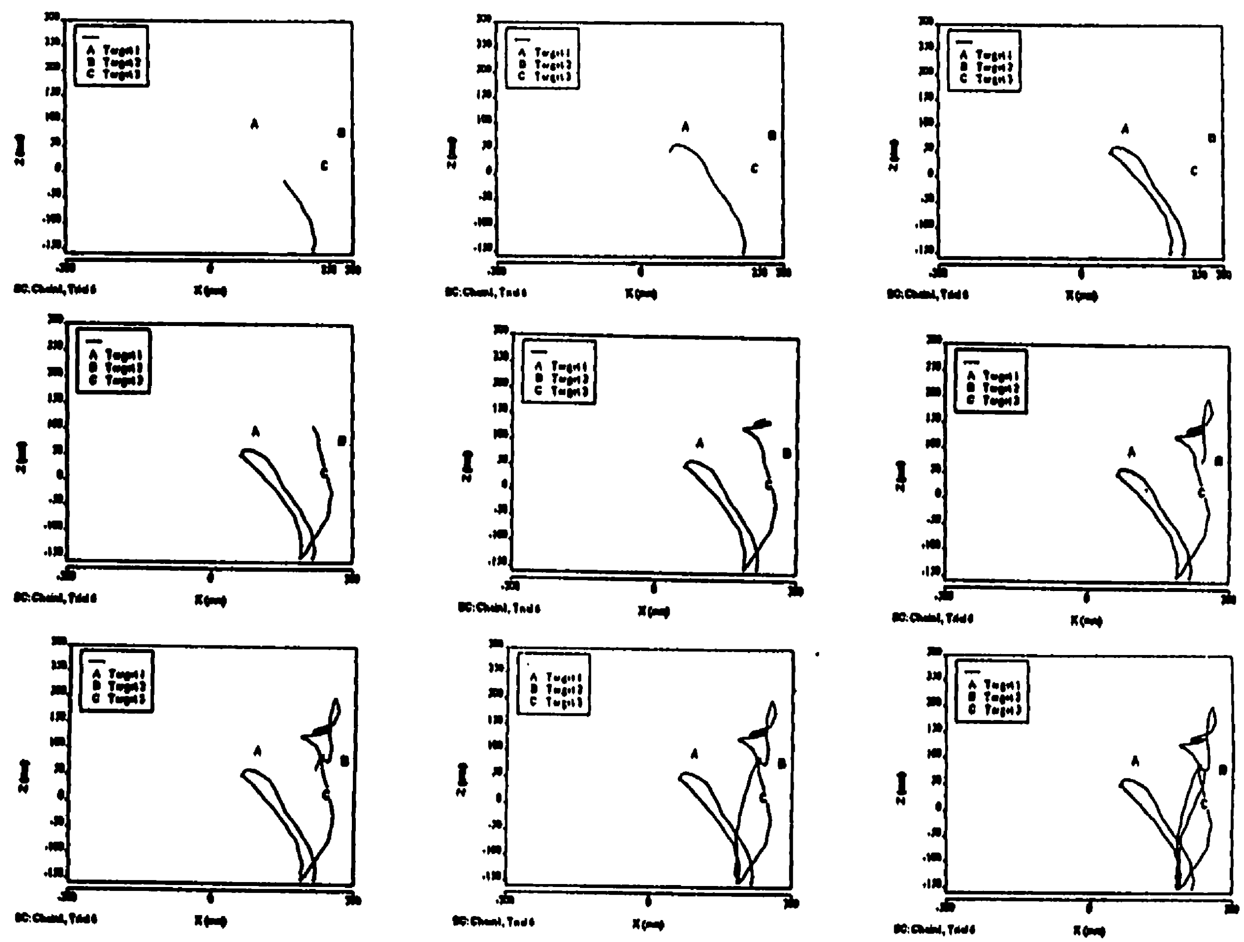

Figure 19. Cumulative x-z coordinate 1 sec frames of responding by Chain1 in test phase of trial 6, under BC procedure. A represents target 1, B represents target 2, and C represents target 3.

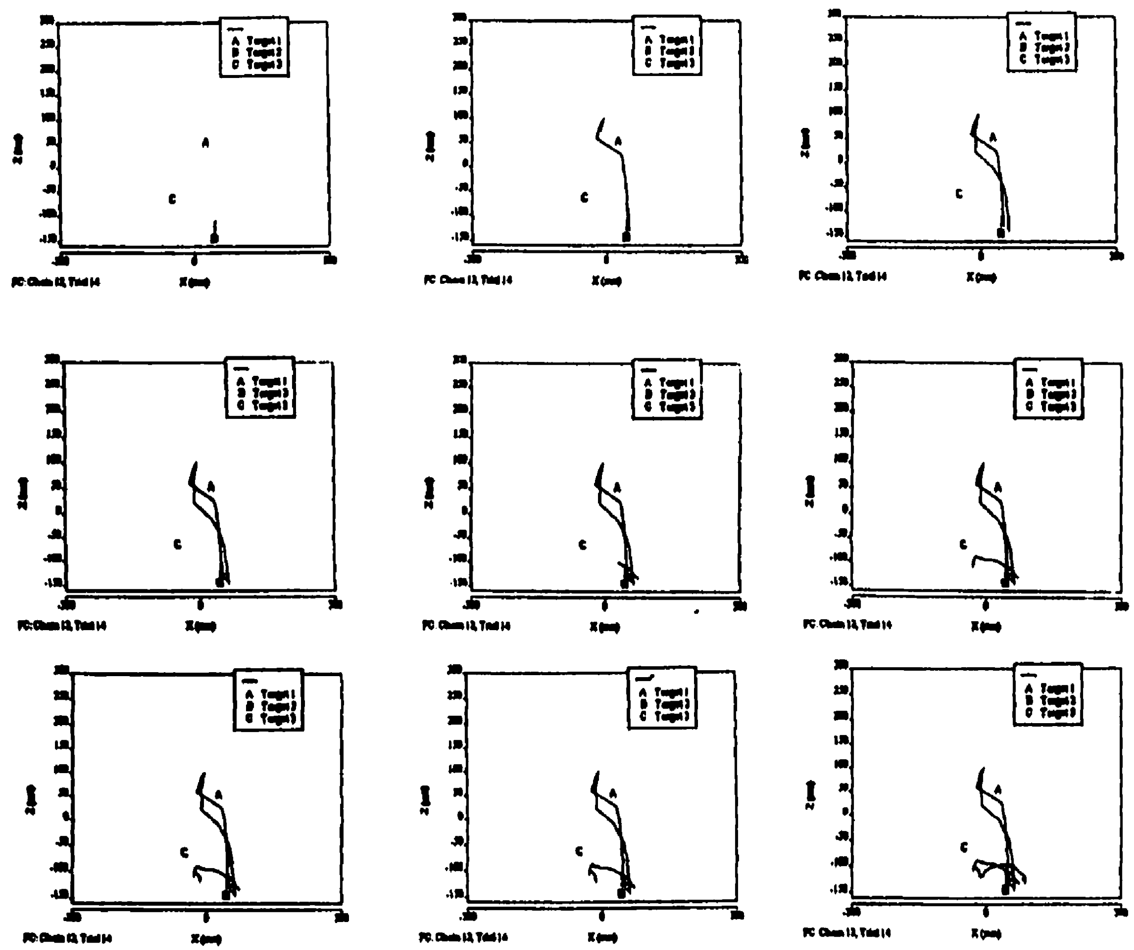

Figure 20. Cumulative x-z coordinate 1 sec frames of responding by Chain12 in test phase of trial 14, under FC procedure. A represents target 1, B represents target 2, and C represents target 3.

toward Target 1 is preceded by movement at Target 2, then back to Target 2, over to Target 3, and back again to Target 2. It could be that this strategy is representative of some kind of landmark.

Discussion

The most important finding is that all three chaining procedures, in combination with shaping parameters, resulted in all participants learning the sequence of responses. In general, BC appears to produce faster training, and more often results completion of training and test phases relative to FC. This finding is not consistent with the previous literature, which suggests no systematic differences between these two procedures (Ash & Holding, 1990; Piscareta, Spooner, 1984; Walls et al., 1981). Why does the current study indicate a difference, when none appeared to occur previously? There may be several reasons for this.

First, the current study involved a different task for assessing differences between the procedures. As such, it is more difficult to identify "errors" (e.g., Walls, et al., 1981). In order to identify an error, we might look at how often an individual moved through an out - of - sequence target (e.g., movement to Target 1 when Target 2 is currently active). However, this might be a problematic definition of "error" if a particular pattern of responding develops which is effective for relocating the targets in the sequence. For instance, the current study reveals that two participants developed a "starting position" strategy during the task which facilitated learning the position of the three targets, while another participant developed an L-shaped pattern. In all three cases, the strategies were effective in producing the responses required for target and component reinforcement, yet required more energy expenditure to do so. While the most efficient manner to repeat the sequence involves making a closed triangle through all three targets, the patterns observed here suggest that what was considered an error for Walls et al.'s task is not as clear - cut for the present study.

A second difference is that the present study uses an automated procedure which allows for more precise specification of the shaping and chaining parameters. This change in apparatus opens up exciting avenues to pursue in future research. For instance, research on developing the procedure and discovering whether any differences between algorithm chaining and hand chaining exist will add important information to the body of literature in the area of chaining procedures.

Another difference is that the current study can more readily assess the average time per target response within conditions, whereas such precision may not have been as easy to obtain in more applied settings. Thus, differences that existed in the training phases may not have been as obvious in previous work.

While it is true that for half of the participants, there was no difference in the percentage of completed training and test phases, for the other half BC did generally result in more completed phases. It may be that the 5 minute constraint on each trial to complete all eight components restricted the percentage of completed phases. However, such a restraint allowed us to consider which condition was more likely to result in completed phases during such a restricted time. Such information may be important if one is considering which procedure to use in a time-limited setting. Another factor that may have caused fewer completed components during the test phase was the absence of shaping during that phase.

Finally, the presence of precise shaping parameters may have resulted in increasing the effectiveness of both procedures. Perhaps under optimal conditions BC is more effective than FC. If so, then further research should consider various shaping parameters in combination with these chaining procedures to determine whether the functional relationships suggested in the present research hold up under such conditions.

The comparisons between FC and TTC and between BC and TTC appear to be more consistent with the literature (Ash & Holding, 1990; Spooner, 1984; Zane, et al., 1981; Walls, et al., 1981; Walls, et al., 1984): FC and BC generally resulted in better outcomes on several measures. It is also interesting that target hit rates usually increased most often under the TTC condition, which is consistent with Spooner's work. Again, I would posit that the reason for this may be that during the training phase target response rates had more room to move in the test phase than did the BC and FC response rates.

FC almost always resulted in more completed training and test phases than did TTC, and where this was not true, they were equal. In contrast, there were no consistent differences on these measures between BC and TTC. This seems to be inconsistent with the comparison between BC and FC, since BC resulted in the same, or greater, percentage of completed training and test phases. If BC was always more effective than FC, then we would expect that BC would result in an equal, or greater, number of completed training and test phases than TTC (since FC results in such a finding). Since this is not the case, we might assume that there an interaction effect is present: each of the procedures may differentially affect the outcome when compared with a different procedure. Further research will need to be done to establish whether or not a functional relationship remains stable between these three procedures.

The present study also suggests that we must consider carefully how reinforcement contingencies might affect the topography of the chained responses. For instance, in an applied setting it may be reasonable to expect a handrest between target hits. However, in some situations where a particular movement is required without stopping, it may not be prudent to develop such a pattern of responding. Further, responding at a different link in the expected sequence of responses may be efficient for orienting, but it may not be effective in all situations. Further research will be required to determine under what conditions individuals are most likely to develop such discontinuous sequences of responding. Systematic findings in that area could help identify the best way to arrange contingencies of reinforcement in chaining procedures.

In conclusion, the overall findings suggest that any of the procedures as carried out in this study result in learning a chain of responses in 3-D space. As such, it would be important to continue this research to the benefit of those who require rehabilitation of limb movement. The technology offers an exciting and dynamic approach to limb movement training, while allowing for a systematic study of same.

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Appendix A

Key Terms

Chaining. Chaining is easy to conceptualize when we consider a linked fence (Martin & Pear, 1996) -- the fence is only as strong as the links holding it together. Often, responses occur in a linear series, rather than as isolated behavioral units, and one response takes on discriminative stimulus properties for the next response (Keller & Schoenfeld, 1950; Skinner, 1938). Similarly, as we shall see, responses in a chain take on the properties of conditioned reinforcers.

As mentioned, reinforcement is simply an event that, when occurring after a response, increases the probability that the response will occur again (i.e., it "strengthens" a particular response). Chaining procedures (also referred to as stimulus-response chaining) use reinforcement to get a new response to occur (Martin & Pear, 1995). As mentioned, it is not just a response that occurs, but a distinct series of responses. Each response in the chain of responses acts as a stimulus for the next response, until the final response in the chain, which is reinforced.

There are three main procedures available to train a sequence of chained behaviors: Forward Chaining (FC), Backward Chaining (BC), and Total Task Chaining (TTC). The first two procedures (FC and BC) are recursive in nature: The procedures require repetition of the sequence in either a forward-moving or backward-moving manner. The TTC method can involve repetition, but it is of the entire chain on each training trial. I will now turn to a more in-depth explanation of each of the three procedures.

Forward Chaining (FC). In this procedure, all components of the chain are trained in order, but in a recursive manner. Here, the first response in the chain is trained first, and reinforced. Next, the first response is repeated and then linked with the second response prior to reinforcement. This method continues until all components of the chain have been trained. A FC procedure might be used to train a new bank teller to balance at the end of their work day (i.e., when there is 30 minutes left in the work day). The main responses can be broken down into: (a) clearing cheques and bill payments (b) recording counts of all paper and coin currency in the teller drawer, and adding up all columns of recorded amounts , and (c) determine if the teller is balanced or not, according to computer records. The stimuli for each response in the chain would be: (a) clock indicating 30 minutes are left in the work day, (b) clearing cheques and bill payments and (c) recording counts and adding columns. The sequence would occur in the same order each day at the end banking, and is trained in this manner. If the teller is balanced, then the supervisor may provide reinforcement in the form of verbal praise, and/or written evaluation. In the bank teller example, the components of an FC procedure might be trained as follows:

(S1) End of Day ⇒ Response 1 (R1): Clearing cheques and bills (Reinforcement)

(R1): Clearing cheques and bills (S2) ⇒ (R2) Record and add cash (Reinforcement)

(R1): Clearing cheques and bills (S2)(R2) Record and add cash ⇒(S3)(R3) balanced? (Reinforcer)

Note that in this example, training would take place over successive days, since it would be difficult to clear cheques and bills more than once for a particular teller. Notice also that each response in the chain is reinforced during each phase of training, thus increasing the likelihood of those responses in the future. As each response is progressively added to the chain, reinforcement occurs only after the final response in each component. Thus, the emitting of the entire component trained is reinforced, thereby increasing the likelihood of the component(s) occurring again. Again, the reinforcement at the end of the entire chain maintains subsequent repetition of the linear order of the chain, once it is established.

Backward Chaining. In this procedure, the recursive nature of the training is in the reverse order to that used in FC procedures. The last response in the chain is trained first, then the second last is chained to the last, and finally the first response is chained to the final two responses. Thus, in the teller example, the following might be used to BC balancing responses:

(S1) End of Day ⇒ Response 3 (R3): Balanced? (Reinforcement)

(S1) ⇒ (R2) Record and add cash ⇒(S2)(R3) Balanced? (Reinforcement)

(S1) ⇒ (R1): Clearing cheques and bills (S2)(R2) Record and add cash ⇒(S3)(R3) balanced? (Reinforcement)

Here, the final response has been reinforced first. Each subsequent response that is trained on subsequent days is chained to the final response, which has an increased likelihood of occurring again. As Martin and Pear (1996) point out, this type of training appears to be "backwards" from how we might normally think to train a linear order of responses. However, notice that in a BC procedure, the final response is already reinforced. Thus, the development of precursor responses in the chain is strengthened through the use of conditioned reinforcement.

Total Task Chaining. This procedure involves training all the responses in a particular sequence each time. The manner in which the components of the chain could function in the bank teller example are as follows:

Stimulus 1 (S1) End of Day ⇒ Response 1 (R1): Clearing cheques and bills

(S2) Clearing ⇒ (R2) Record and add cash

(S3) Record and add cash ⇒ (R3) balanced?

(Reinforcement)

Thus, we can see that the end of day can act as an SD to begin the chained responses for balancing. Over a number of sequences, the final response (balancing) is chained to the immediately preceding response, thus resulting in the former becoming a conditioned reinforcer for the second response. The same relationship develops between the first and second responses, as a function of their relationship to the third response. The reinforcement at the end of the sequence is the "oil" that keeps the chain moving smoothly (Martin & Pear, 1996).

Similarities and differences in the three procedures. Miltenberger (1997) points out that all three of these procedures have similarities and differences. First, all are used to teach chains of behavior, as described in the bank teller example. Second, they require task analysis (breaking down the chain into its component parts), prompting and fading. Differences in the procedures are broken down into the following: (a) FC and BC differ from TTC in that in TTC the entire task is presented on each trial, while FC and BC train one component at a time, and then link them together, (b) FC is different from BC in that BC completes the chain in each trial, and the final reinforcer is provided, and (c) FC, as compared to BC, may use different reinforcers for earlier components of the chain, until the last behavior of the chain is linked to the other components.

Discriminative stimuli. Discriminative stimuli act as signals, or cues, to indicate when a particular response will result in reinforcement (Martin & Pear, 1995). The example Martin & Pear use is that of a teenager who uses profane language. In the presence of his/her friends, swearing may be consequated by laughter, praise, et cetera, which could serve to reinforce the swearing behavior. However, in the presence of parents and grandparents, the teenager's swearing does not receive reinforcement (in fact, punishment may even follow such verbal behavior). Thus, the teenager's friends act as a discriminative stimulus to swear, since that behavior is likely to be reinforced. In contrast to discriminative stimuli, S-Deltas indicate that responses will not be reinforced (i.e., extinction or nonreinforcement consequate behavior). Thus, the presence of the teenager's parents and grandparents act as an SΔ for swearing, since that behavior is not likely to be reinforced in that situation.

Note that in the above situation, the teenager can learn to respond appropriately through contingencies alone. However, if he/she learns to state the contingencies, and act on that statement, then his/her behavior can be called rule-governed.

Extinction. In order to decrease the probability of a response from occurring again, extinction may be used. In this procedure, a response which was previously reinforced is no longer reinforced (Skinner, 1938; Skinner, 1953). The subsequent result is that the response will become less likely to occur again in a similar situation. Notice that this principle operates according to the three-term contingency outlined for reinforcement. Extinction is different from reinforcement in that there is a removal of a previously-occurring reinforcer when responding occurs, and the subsequent effect is to decrease the probability of responding again in a similar situation. For example, assume that a particular student answers quite a few questions put to an entire classroom. Now, if the teacher no longer calls upon this student to answer questions, eventually the student will stop answering questions. An important aspect of extinction is that the behavior is likely to increase before it diminishes. Thus, the student is likely to make noises, snap their fingers, or even shout "Oh! I know it!" prior to the point at which they stop answering questions in class. We might refer to this increase as one of variability in responding , since the form of the behavior changes after extinction is applied.

It is important to distinguish the principle of extinction from the principle of punishment. In punishment, an aversive consequence following the occurrence of a particular response results in the decrease of the response in similar situations (Martin & Pear, 1996). Shaping as defined here does not incorporate punishment. Punishment only serves to stop a particular response from occurring -- it does not provide any information on how to respond. In addition, the nature of the way in which extinction affects behavior is integral in the development of a new response. As we will see, variability in responding resulting from extinction is integral in shaping a new response.

Fading is a another procedure used to produce gradual change (Martin & Pear, 1995). Here, reinforcement of closer approximations to a final desired stimulus for a particular response is reinforced. The steps in fading do not necessarily form part of the targeted stimulus control, and involve the successive application of reinforcement (i.e., no extinction is used in fading procedures). For example, fading could be used to teach a child how to say the word "chip" when faced with a potato chip. At the beginning, the trainer could point to the chip and say "What is this?", and then say loudly "Chip!". Reinforcement is provided when the child mimics the word "chip", and on successive trials, the volume of the trainer's utterance of "chip" is reduced, and finally the child says "Chip" when asked "What is this?" while you point at the chip.

Prompts are stimuli used to supplement training, but are not part of a final desired stimulus (Touchette & Howard, 1984). Prompts can be verbal, gestural or physical. All three types of prompts provide a cue (or hint) to person about how to respond. Verbal prompts are uttered by a trainer. For instance, in teaching a child to make a bed, one might say "Now it's time to put the bottom sheet on the bed", and then wait for them to do so. A gestural prompt may also be used in this situation, such as motioning toward the blanket that would go on the bed next (gestural prompts do not include touching the person). Environmental prompts are those stimuli altered in the environment in such a way that they evoke a desired behavior (e.g., a chart of sequential bed-making responses posted above the bed). Finally, physical prompts, or guidance, involve touching the person being trained to guide the response. In the bed-making example, one could put their hand over the hand of a child when they are learning to tuck in the corners of a sheet. Note that the prompting procedures are not mutually exclusive: All of these may be used in any combination, and eventually faded from the sequence of behaviors such that responding occurs without many of these prompts.

Reinforcement. This is the term used to refer to a relationship that exists when, in a given situation, a response is followed by an event, and that response subsequently increases in probability in similar situations (Skinner, 1938; Skinner, 1953). This relationship is referred to as the three term-contingency (Martin & Pear, 1996), incorporating an antecedent (the situation), the response, and the consequence. When individuals respond according to three-term contingencies, we may say that their behavior is contingency - based. However, if an individual can state the contingency, and act according to the statement, we may refer to such behavior as rule-governed. For instance, if you have trouble with a key in a door lock, and you jiggle the key around such that the door finally opens, you are more likely to jiggle that key in that lock. In fact, when faced with other door locks that are difficult to open (e.g., a car-door), you might even attempt the key-jiggling response again (this transfer of a response to a similar situation is referred to as generalization). The antecedent condition is a door lock that is difficult to open, the response is jiggling the key in the lock, and the consequence is unlocking the door.

A note on confusing rewards with reinforcement seems important at this point. Not all students will respond in the manner described above, based upon grade alone. For some students, praise may have more effect on their subsequent behavior than the actual grade in the course. For various reasons associated with our unique behavioral histories (Hayes, 1992), different people will respond differently to different consequences for their behavior. In short, a consequence for a given response may be regarded as reinforcing if and only if subsequent responding increases, when that behavior has been followed by the given consequence in the past. The principle of reinforcement is a definition that explains the relationship existing between a response and its outcome in a given situation, and the subsequent probability of reinforcement in a similar situation again.

Martin and Pear (1996) point out that reinforcers can be primary, or reinforcing in and of themselves. Examples of primary reinforcers include water and food, which are basic to survival. Secondary (or conditioned) reinforcers are events or stimuli that have been paired with primary reinforcers, such that they take on the properties of a reinforcer. Pairing caresses during feeding results in caresses becoming secondary reinforcers. Similarly, praise is paired with other reinforcers as children grow up. Thus, praise for appropriate behavior is often a strong reinforcer in society. Failure to pair other reinforcers, such as praise can result in a failure to learn without primary reinforcers. In a society that uses secondary reinforcers, such individuals may be regarded as developmentally delayed.

Shaping. Shaping is defined as the reinforcement of successive approximations to a targeted behavior (Skinner, 1953), and has been used to shape many behaviors such as limb movement in stroke victims (Taub et al., 1994) and the hand-held position of a stylus in three-dimensional space (Pear, et al., 1996). Shaping is used to modify responding until a targeted behavior occurs. Skinner points out that when a particular response is shaped, there is nothing sudden about the novel behavior -- it occurs based upon the previous approximations in responding toward the goal. However, this does not preclude movement toward the targeted behavior during shaping from occurring abruptly, since once movement is reinforced, it is more likely to occur again. The original probability of the novel response is very low, or even at zero when starting out. Chiesa (1994) suggests that shaping best illustrates selection in action: An observed behavior successively reinforced is selected by reinforcing consequences, until the production of a reliable relation between behavior and consequence occurs. Thus, the three-term contingency describes the natural-selection process, and the understanding of these processes through behavior analysis has resulted in the successful application of shaping as a procedure.

Shaping uses two of the principles outlined above to increase the probability of a novel response occurring: reinforcement and extinction (Martin & Pear, 1996). A response that in some way resembles the final targeted behavior is reinforced at the beginning of the procedure. The next step is to put that response on extinction, and raise the criterion for reinforcement closer to the targeted response. Galbicka (1994) suggests four main concerns in the shaping process. First, you must start where the organism begins responding. That is, the first response is the starting point from which the criterion for reinforcement shifts toward the targeted behavior. Second, the terminal response must be clearly defined, in order to facilitate the determination of steps requiring mastery to reach the end goal. If the goal is imprecise, then specifying the steps to achieve it will be difficult indeed. Third, it is best to use small steps to change the criterion for reinforcement, such that that responding will not come under too high an extinction rate. If extinction were to occur for too long, then one risks losing the behavior already established in the shaping sequence. Thus, it behooves the behavior modifier to use sufficiently small steps to ensure behavior is maintained. Finally, movement should be reinforced, rather than position. This concept is in agreement with researchers (e.g., Pear, et al., 1996; Skinner, 1953), who suggest that it is the differentiation of responding that is required for shaping. Indeed, effective shaping would seem to require some sort of variability in responding in order that movement toward the target behavior would be more likely. Thus, in programming an effective shaping algorithm, one must ensure that responses are sufficiently variable so that movement is reinforced.

Appendix B

Instructions to Participants

- Your task is to locate a number of invisible targets in a particular sequence. The computer selects these targets, and indicates when you are getting closer to a particular target by making a tone sound. The tone will not sound as you move further away. When you make contact with a target, you will notice a different tone sounds. Sometimes when you contact a target, a completely different tone will also sound. This additional tone indicates that you have earned one point.
- Sometimes, the computer program may have you repeat an already-learned target to ensure you have learned it sufficiently. If you have previously encountered a target, and the computer requires you to find it again, you will not earn points for that target again. Instead, you will hear the different tone you heard previously that indicates you have found the target. Once you find a different target, you will earn another point. The computer screen directly in front of you will display the target number in the sequence that you are currently learning.
- Once you have found all the targets, the program will require that you repeat the sequence a number of times to ensure you have learned it.
- The object of this part of the experiment is to train you to find a number of targets, and then test to see if you have learned the sequence in which they must be hit. Keep trying to find the targets and/or repeat the sequence in which you learned them until I ask you to stop. This part of the experiment will end when I indicate so, or when you have earned 8 points, whichever occurs first.
- At any point in the trial, you can rest your arm on the table.
- Are there any questions?

Appendix C: Summaries of Trial Data for Each Participant

BC versus FC

Participant	Trial	Condition	Points	Test Time	Train Time	Avg Test	Avg Train
Chain4	1	BC	3	56.80	240.70	N/A	80.23
	2	FC	6	226.90	70.70	75.63	23.57
	3	BC	8	129.40	63.70	25.88	21.23
	4	FC	2	0.00	297.60	N/A	148.80
	5	BC	8	53.60	78.30	10.72	26.10
	6	FC	3	135.30	162.20	N/A	54.07
	7	BC	4	156.90	140.70	156.90	46.90
	8	FC	8	48.70	51.90	9.74	17.30
	9	BC	8	32.30	42.80	6.46	14.27
	10	FC	7	224.60	73.00	56.15	24.33
	11	BC	8	31.50	36.70	6.30	12.23
	12	FC	8	42.60	74.20	8.52	24.73
	13-16	Data Lost					
Chain5	1	FC	0	0.00	297.50	N/A	N/A
	2	BC	4	64.30	233.20	64.30	77.73
	3	FC	4	161.40	136.10	161.40	45.37
	4	BC	2	0.00	297.60	N/A	148.80
	5	FC	8	150.80	108.80	30.16	36.27
	6	BC	8	88.70	145.80	17.74	48.60
	7	FC	8	45.10	59.20	9.02	19.73
	8	BC	3	29.20	268.40	N/A	89.47
	9	FC	8	51.70	98.90	10.34	32.97
	10	BC	8	55.50	70.60	11.10	23.53
	11	FC	8	95.80	51.70	19.16	17.23
	12	BC	8	65.30	107.30	13.06	35.77
	13	FC	8	43.60	52.70	8.72	17.57
	14	BC	8	62.60	77.00	12.52	25.67
	15	FC	8	108.20	121.30	21.64	40.43
	16	BC	8	42.00	43.90	8.40	14.63
	17	FC	7	82.10	215.40	20.53	71.80
	18	BC	8	64.70	60.80	12.94	20.27

Participant	Trial	Condition	Points	Test Time	Train Time	Avg Test	Avg Train
Chain10	1	BC	8	55.00	90.10	11.00	30.03
	2	FC	2	0.00	297.60	N/A	148.80
	3	BC	8	90.60	173.50	18.12	57.83
	4	FC	8	64.70	168.20	12.94	56.07
	5	BC	3	13.20	284.40	N/A	94.80
	6	FC	6	133.70	163.90	44.57	54.63
	7	BC	Data Lost				
	8	FC	Data Lost				
	11	BC	8	105.50	60.40	21.10	20.13
	12	FC	8	86.90	71.60	17.38	23.87
	13	BC	8	113.80	56.20	22.76	18.73
	14	FC	8	80.10	140.80	16.02	46.93
	15	BC	7	232.30	65.30	58.08	21.77
	16	FC	8	75.40	85.50	15.08	28.50
	17	BC	8	67.10	98.20	13.42	32.73
	18	FC	8	175.30	79.70	35.06	26.57
Chain11	1	FC	4	87.20	210.30	87.20	70.10
	2	BC	3	151.20	146.30	N/A	48.77
	4	FC	8	140.90	82.80	28.18	27.60
	3	BC	8	81.70	83.30	16.34	27.77
	5	FC	8	77.40	90.50	15.48	30.17
	6	BC	8	128.90	116.90	25.78	38.97
	7	FC	8	90.60	48.10	18.12	16.03
	8	BC	8	82.30	100.20	16.46	33.40
	9	FC	8	55.30	66.20	11.06	22.07
	10	BC	8	78.70	66.10	15.74	22.03
	11	FC	3	179.50	118.10	N/A	39.37
	12	BC	8	47.00	52.10	9.40	17.37
	13	FC	8	56.40	89.20	11.28	29.73
	14-18	Data Lost for all Trials in Range					

FC versus TTC

Participant	Trial	Condition	Points	Test	Train	Avg Test	Avg Train
Chain2	1	FC	4	93.40	204.20	93.40	68.07
	2	TTC	1	0.10	297.50	N/A	297.50
	3	FC	2	0.10	297.50	N/A	148.75
	4	TTC	8	56.40	154.50	11.28	51.50
	5	FC	8	48.90	69.10	9.78	23.03
	6	TTC	3	29.20	268.40	N/A	89.47
	7	FC	3	99.50	198.10	N/A	66.03
	8	TTC	8	62.30	143.90	12.46	47.97
	9	FC	8	48.20	65.00	9.64	21.67
	10	TTC	8	45.10	117.30	9.02	39.10
	11	FC	4	226.90	70.60	226.90	23.53
	12	TTC	0	0.00	297.60	N/A	N/A
	13	FC	8	189.80	52.70	37.96	17.57
	14	TTC	Data Lost				
	15	FC	8	39.40	37.80	7.88	12.60
	16	TTC	8	52.60	126.70	10.52	42.23
	17	FC	8	86.80	166.00	17.36	55.33
	18	TTC	3	5.30	292.30	N/A	97.43
	19	FC	8	84.20	63.60	16.84	21.20
	20	TTC	8	48.70	106.40	9.74	35.47
Chain6	1	TTC	2	0.00	297.30	N/A	148.65
	2	FC	8	121.30	109.40	24.26	36.47
	3	TTC	5	193.30	104.30	96.65	34.77
	4	FC	7	183.70	113.90	45.93	37.97
	5	TTC	1	0.00	297.60	N/A	297.60
	6	FC	6	134.80	162.80	44.93	54.27
	7	TTC	8	71.00	201.90	14.20	67.30
	8	FC	8	174.70	83.90	34.94	27.97
	9	TTC	8	55.40	114.60	11.08	38.20
	10	FC	8	78.50	75.70	15.70	25.23
	11	TTC	8	81.40	114.60	16.28	38.20
	12	FC	8	62.40	72.30	12.48	24.10
	13	TTC	8	82.10	153.00	16.42	51.00
	14	FC	8	40.20	75.40	8.04	25.13
	15	TTC	8	46.30	178.60	9.26	59.53
	16	FC	8	72.00	121.00	14.40	40.33
	17	TTC	8	26.40	46.70	5.28	15.57
	18	FC	8	37.50	60.00	7.50	20.00
	19	TTC	8	27.70	124.40	5.54	41.47
	20	FC	8	29.80	63.20	5.96	21.07

Participant	Trial	Condition	Points	Test Time	Train Time	Avg Test	Avg Train
Chain8	1	FC	8	98.00	59.50	19.60	19.83
	2	TTC	7	185.10	112.50	46.28	37.50
	3	FC	8	61.00	52.60	12.20	17.53
	4	TTC	6	203.50	93.90	67.83	31.30
	5	FC	8	40.40	38.00	8.08	12.67
	6	TTC	5	118.30	179.30	59.15	59.77
	7	FC	8	58.60	36.50	11.72	12.17
	8	TTC	8	85.10	122.40	17.02	40.80
	9	FC	8	133.40	95.40	26.68	31.80
	10	TTC	Data Lost				
	11	FC	Data Lost				
	12	TTC	Data Lost				
	13	FC	8	39.30	42.50	7.86	14.17
	14	TTC	8	58.00	45.70	11.60	15.23
	15	FC	8	29.60	42.10	5.92	14.03
	16	TTC	8	42.00	112.00	8.40	37.33
	17	FC	8	29.70	159.20	5.94	53.07
	18	TTC	8	60.30	211.30	12.06	70.43
	19	FC	8	101.60	64.70	20.32	21.57
	20	TTC	Data Lost				
Chain12	1	TTC	4	12.70	284.80	12.70	94.93
	2	FC	4	239.10	58.50	239.10	19.50
	3	TTC	8	60.20	127.40	12.04	42.47
	4	FC	8	116.70	37.40	23.34	12.47
	5	TTC	8	79.50	169.10	15.90	56.37
	6	FC	8	77.10	43.70	15.42	14.57
	7	TTC	8	88.40	96.40	17.68	32.13
	8	FC	8	135.70	64.30	27.14	21.43
	9	TTC	2	0.00	297.60	N/A	148.80
	10	FC	4	41.90	255.40	41.90	85.13
	11	TTC	1	0.00	297.60	N/A	297.60
	12	FC	6	141.40	156.20	47.13	52.07
	13	TTC	8	61.00	120.00	12.20	40.00
	14	FC	8	123.00	25.80	24.60	8.60
	15	TTC	8	129.90	60.30	25.98	20.10
	16	FC	8	41.30	50.20	8.26	16.73
	17	TTC	6	205.10	92.40	68.37	30.80
	18	FC	0	0.00	297.50	N/A	N/A

BC Versus TTC

Participant	Trial	Condition	Points	Test Time	Train Time	Avg Test	Avg Train
Chain1	1	TTC	0	0.00	297.50	N/A	N/A
	2	BC	0	0.00	297.60	N/A	N/A
	3	TTC	3	0.20	297.30	N/A	99.10
	4	BC	6	210.70	86.80	70.23	28.93
	5	TTC	8	86.40	202.60	17.28	67.53
	6	BC	8	44.70	144.50	8.94	48.17
	7	TTC	6	185.90	111.70	61.97	37.23
	8	BC	8	214.70	67.80	42.94	22.60
	9	TTC	8	61.10	121.70	12.22	40.57
	10	BC	8	46.00	106.00	9.20	35.33
	11	TTC	8	58.00	223.10	11.60	74.37
	12	BC	8	36.90	39.50	7.38	13.17
	13	TTC	8	47.20	45.20	9.44	15.07
	14	BC	8	93.10	73.20	18.62	24.40
	15	TTC	8	45.30	201.00	9.06	67.00
	16	BC	8	160.10	76.80	32.02	25.60
	17	TTC	8	52.10	116.30	10.42	38.77
	18	BC	8	60.30	71.80	12.06	23.93
	19	TTC	8	38.90	44.90	7.78	14.97
	20	BC	8	52.20	45.10	10.44	15.03
Chain3	1	BC	3	20.00	277.60	N/A	92.53
	2	TTC	4	36.60	261.00	36.60	87.00
	3	BC	8	61.10	90.20	12.22	30.07
	4	TTC	8	63.20	128.00	12.64	42.67
	5	BC	2	0.00	297.60	N/A	148.80
	6	TTC	8	65.00	145.50	13.00	48.50
	7	BC	3	83.10	214.40	N/A	71.47
	8	TTC	8	183.80	90.80	36.76	30.27
	9	BC	5	193.80	103.70	96.90	34.57
	10	TTC	8	66.90	125.90	13.38	41.97
	11	BC	3	0.00	296.10	N/A	98.70
	12	TTC	8	85.10	50.90	17.02	16.97
	13	BC	8	149.00	120.90	29.80	40.30
	14	TTC	5	169.00	128.50	84.50	42.83

Participant	Trial	Condition	Points Earned	Test Time	Train Time	Avg Test	Avg Train
Chain7	1	TTC	0	0.00	297.60	N/A	N/A
	2	BC	5	228.00	69.60	114.00	23.20
	3	TTC	3	8.70	288.90	N/A	96.30
	4	BC	8	68.70	124.80	13.74	41.60
	5	TTC	8	97.30	124.70	19.46	41.57
	6	BC	3	12.00	285.60	N/A	95.20
	7	TTC	8	72.40	148.40	14.48	49.47
	8	BC	8	71.80	61.30	14.36	20.43
	9	TTC	8	116.50	112.10	23.30	37.37
	10	BC	8	94.10	107.50	18.82	35.83
	11	TTC	8	62.70	125.90	12.54	41.97
	12	BC	1	0.00	297.60	N/A	297.60
	13	TTC	3	24.70	272.90	N/A	90.97
	14	BC	6	94.40	203.20	31.47	67.73
	15	TTC	8	71.10	79.30	14.22	26.43
	16	BC	8	50.70	86.10	10.14	28.70
	17	TTC	3	3.40	294.10	N/A	98.03
	18	BC	8	53.10	63.30	10.62	21.10
Chain9	1	BC	3	125.90	171.60	57.20	N/A
	2	TTC	8	81.70	62.10	16.34	20.70
	3	BC	8	81.20	118.50	16.24	39.50
	4	TTC	8	51.70	122.80	10.34	40.93
	5	BC	8	35.50	65.50	7.10	21.83
	6	TTC	8	62.00	89.80	12.40	29.93
	7	BC	8	106.20	42.50	21.24	14.17
	8	TTC	8	55.50	57.10	11.10	19.03
	9	BC	8	101.80	194.90	20.36	64.97
	10	TTC	8	53.70	95.30	10.74	31.77
	11	BC	Data Lost				
	12	TTC	8	73.00	51.20	14.60	17.07
	13	BC	8	38.50	108.50	7.70	36.17
	14	TTC	8	33.70	74.80	6.74	24.93
	15	BC	8	153.40	85.90	30.68	28.63
	16	TTC	8	31.10	108.50	6.22	36.17
	17	BC	6	238.40	59.20	79.47	19.73
	18	TTC	8	102.60	178.00	20.52	59.33