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# Model-guided line drawing in the chimpanzee (*Pan troglodytes*)[1]

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**Abstract:** Two female chimpanzees (*Pan troglodytes*) had been taught previously to draw straight lines on a touch-sensitive monitor with a method of electronic finger painting. Both subjects could accurately connect two guide dots on the monitor by placing the finger at one dot (startdot) and moving the finger over to the other dot (stopdot), thereby leaving a trace of "electronic ink" on the monitor that followed the orientation of the dots (horizontal, vertical, or diagonal). In Experiment 1, the subjects were connecting the two guide dots while a model (a 12-cm bar) was placed next to them. Probe trials tested whether this model would guide drawing when one or both of the dots were removed. One subject was able to draw parallel to the model on some of the test trials without the stopdot while the other subject showed no such behavior. In Experiment 2, the latter subject was explicitly trained to draw parallel to the model while the stopdot was gradually faded away. In an attempt to improve accuracy of drawing parallel to the model for both subjects, Experiment 3 presented only three models (vertical and the two diagonals) and one startdot location; in addition, the subjects could make multiple strokes on each trial. Both subjects, especially the chimpanzee given extra training in Experiment 2, were able eventually to draw a trace that was guided by and therefore parallel to the model. The results provide evidence that the chimpanzee can be taught a simple form of structured drawing guided by a model. The fully automated recording and teaching method induced quite accurate elementary copying behavior in chimpanzees without the use of verbal instruction, demonstration, or manual assistance.

**Key words:** chimpanzee, drawing, electronic finger painting, fading, copying, parallel lines, automated teaching.

When young children have passed the scribbling stage of drawing, they usually begin to trace lines and to draw simple copies of a model (e.g., Cratty & Martin, 1969). To examine the ability to copy, an object is shown at one location as the model, and the child is instructed to draw the model on a piece of paper adjacent to or distant from the model. If the drawing surface is transparent and placed at the same location as the model (e.g., on top

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of the model) the task commonly is called tracing. Studies of tracing and copying in human children rely on already established linguistic repertoires regarding execution of the verbal instruction employed by the experimenter (e.g., Mitchelmore, 1985; Piaget & Inhelder, 1967) and on demonstration and assistance (e.g., Rand, 1973).

Previous work on drawing with nonhuman primates has shown that captive apes spontaneously draw with markers, paint brushes, or with their fingers (Boysen, Berntson, & Prentice, 1987; Morris, 1962; Schiller, 1951; Smith, 1973). The apes primarily scribble, with only occasional evidence of spontaneous visual control of drawing, such as marking objects on the writing surface (Schiller, 1951).

In a recent study we taught two chimpanzees to draw straight lines with an automated method of electronic finger painting (Iversen & Matsuzawa, 1996). The subjects faced a touch-sensitive monitor, and movement of the finger over the monitor surface generated "electronic ink" in the form of a small disk at the touched location. After training, the subjects reliably connected two dots presented on the monitor by placing a finger on one dot and moving the finger over the surface until it reached the second dot, thereby generating a visible trace of electronic ink that stayed on the monitor until the trial was over. The dots were presented in different orientations. The distance between the dots and their orientation guided the drawing such that the length of the drawn trace matched the distance between the dots, and the slope of the trace matched the slope of an imaginary line between the dots.

The objective of the present experiments was to explore teaching methods that may enable a chimpanzee to draw a copy of a model. The simplest form of copying is perhaps to draw a line parallel to another line already drawn. The subject is shown one model line, and the task is to copy the model by drawing a second line next to it. In this task, a correctly drawn copy has at least two features: it is parallel to the model, and the length of the copy matches the length of the model. A third feature may be that the endpoints of the copy should be aligned with the endpoints of the model. The task we presented to the chimpanzees was to draw a line parallel to a model presented on the monitor. The subjects had already learned to draw a line that connected two dots (Iversen & Matsuzawa, 1996). We built upon this visual guidance of drawing behavior by presenting an additional visual instruction on the monitor. Our methods are new and exploratory, so we have broken the research process into three experiments that illustrate the successive development of model-guided drawing.

## Experiment 1

Experiment 1 first established the behavior of connecting two guide dots when a bar (the model) was displayed on the monitor. Then three types of probe trials tested whether this training had established the bar as a model. The top display in Figure 1 shows the stimuli on the monitor and how the subjects drew after training. At the start of each training trial the monitor showed a bar and two dots. The two dots were distant from and aligned with the endpoints of the bar. The task for the subject was to aim at one dot, sweep the finger across the monitor surface to the second dot, lift the finger, and then press a white key on the monitor to end the trial. When the trace produced by the subject was correctly drawn, this trial-termination response produced reinforcement. On each trial, the bar and the two dots appeared in one of four orientations. Trial types are referred to by the angle of the model to horizontal (i.e., 0°, 45°, 90°, and 135°). The subjects had been taught previously to draw from right to left on 0° trials and from top to bottom on the remaining trial types.

The question we asked in Experiment 1 was whether the bar would serve as a model for drawing after we removed one or both of the dots. We mixed probe trials with baseline trials that showed the model and both guide dots. The bottom display of Figure 1 shows what the screen looked like at trial start for three types of probe trials. What would the subjects do on such trials? If the subjects were able to draw a

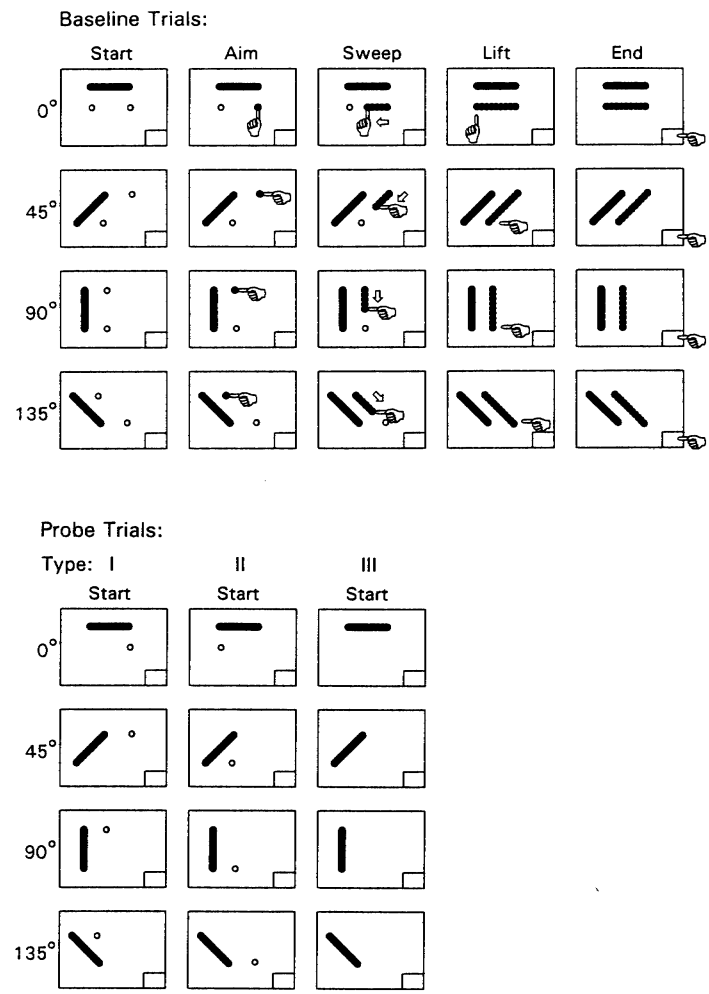


**Figure 1.** The top display presents the four types of baseline trials used in training. Each frame represents an outline of the monitor. A model (dark bar) and two guide dots (small open circles) appeared on the monitor at the start of each trial arranged in one of four orientations. The angle of the model to horizontal is given in the left-hand column. The subject aims at one dot, sweeps the finger over the monitor, lifts the finger at the next dot, and ends the trial by pressing the white key at the lower right-hand corner of the monitor. The bottom display shows what the screen looked like at trial start for the three types of probes that were mixed with baseline trials in test sessions. One or both guide dot(s) were removed from the display to test how the model guided drawing.

line parallel to the model, then the training of connecting two dots next to the model would have proven sufficient to establish the bar as a model for drawing; the subjects would be making a copy of the model.

### *Method*

*Subjects*. We studied two adult female chimpanzees (Ai aged 16 years, Pendesa aged 15 years) who had prior laboratory experience. Ai had considerable experience with free drawing on paper with markers and other material, and both subjects had used a touch-sensitive monitor in matching-to-sample tasks (e.g., Fujita & Matsuzawa, 1990; Kojima & Kiritani, 1989; Matsuzawa, 1985a, 1985b, 1990; Tomonaga & Matsuzawa, 1992). Both subjects had also learned to draw straight lines on a touch-sensitive monitor in a study by Iversen and Matsuzawa (1996). In that and the present study, both subjects spontaneously and exclusively used the right hand for drawing. Subjects were not food deprived and received 100–200 daily training trials. The chimpanzees were kept in a group of seven chimpanzees who live in an outdoor enclosure with an attached indoor residence. They were cared for according to guidelines produced by the Primate Research Institute, Kyoto University.

*Apparatus*. From the outdoor enclosure, subjects entered an experimental booth (150 cm × 180 cm × 200 cm) equipped with a Mitsubishi FHC Vex 21-inch color monitor on one wall. Bits of fruit or candy were delivered automatically as reinforcement into a small cup on the wall to the left of the wall with the monitor. An NEC (Model PC-9801F2) personal computer was used for programming using the QuickBASIC language.

A Microtouch transparent touch screen was integrated with the monitor to enable automatic recording of the location of a touch on the monitor. Each touch generated electronic ink at the touched location. This was a fingertip-sized blue disk (a 32-pixel diameter filled circle). With the monitor used, 100 pixels equalled 5.83 cm. Continuous movement of the finger over the monitor surface thereby produced a visual trace consisting of a series of connected and overlapping blue disks that stayed on the screen for the remainder of the trial.

*Pretraining*. In Iversen and Matsuzawa (1996) we used the same apparatus, and the subjects were trained to draw smoothly on the monitor. After training, the subjects could draw a straight line that connected two dots on the monitor. In brief, this training had progressed from pressing a series of aligned circles that were presented in four orientations (horizontal, vertical, and the two diagonals). By moving the circles closer and closer in small steps across sessions, the topography of screen contact changed from pressing each individual circle to smooth connection of all circles in one stroke. The circles were then changed gradually to a line that the subjects traced, and the line was changed gradually to just the endpoints. The training in Iversen and Matsuzawa was described in 10 steps. In step 10 screen contact produced electronic ink at any place on the monitor (except on the trial-termination key). The first phase of the present experiment began in step 10. For the first 15 sessions of step 10 each trial displayed a bar on the monitor in addition to the two guide dots. The bar was 32 pixels wide and blue with rounded ends. The length of the bar and the distance between the two guide dots was fixed at 200 pixels for all trials; the guide dots were white disks 10 pixels in diameter. For details regarding the precise arrangement of the stimuli on the screen see "Exact stimulus descriptions" in the Appendix.

Thus, the subjects were drawing freely on the monitor and produced on each trial a trace that connected the two guide dots. After drawing the trace, the subject had to press the trial-termination key on the monitor to produce reinforcement. Pressing the key caused the program to analyze the drawn trace according to three criteria: length, angle to horizontal, and variability. The trace length had to be within ±40 pixels of the 200-pixel dot distance, the trace angle had to be within ±10° of the angle of the model, and the variability had to be less than 10 pixels. The precise method of analyzing the trace is given in the Appendix under "Reinforcement criteria." When all three criteria were fulfilled, a beeper sounded for 0.5 s, and the subject received a reinforcement in the form of a small piece of fruit and the screen went blank. When reinforcement was not given, the screen went blank after 0.5 s. The intertrial interval was 3 s. In step 10 each session had 96 trials.

*Probe testing*. The screen displays on probe trials are shown in the lower part of Figure 1. After 15 sessions in step 10 (of pretraining), one session introduced probe trials type I, showing the model and only the guide dot that controlled the start point of drawing (hereafter the *startdot*). This session had 72 baseline trials (the model and both guide dots) and six probe trials of each of the four trial (i.e., angle) types. After two sessions with baseline trials only, one more test session presented probe trials type II, showing only the guide dot that controlled the stop point of drawing (hereafter the *stopdot*) along with the model. This session had 24 baseline trials and eight probe trials (two of each trial type). After one session with baseline trials only, a third test session presented probe trials type III, showing only the model and no guide dots; this session had 24 baseline trials and eight probe trials (two of each trial type).

In test sessions, probe trials occurred in mixed order with at least two baseline trials separating probe trials. Because performance on probe trials was not known in advance, we decided to provide manual reinforcement on probe trials. After deciding that drawing on a probe trial should produce reinforcement, the experimenter pressed a key on the keyboard, thereby enabling the trial-termination response to cause reinforcement. The subjective criteria for reinforcement on probe trials were that the drawn trace should be roughly parallel to the model and be at least half the length of the model; an additional criterion was that if several probe trials had passed without reinforcement then any drawing in the appropriate angle would be reinforced. The purpose of providing reinforcement on probe trials was to maintain the overall task design of reinforcement on nearly all trials.

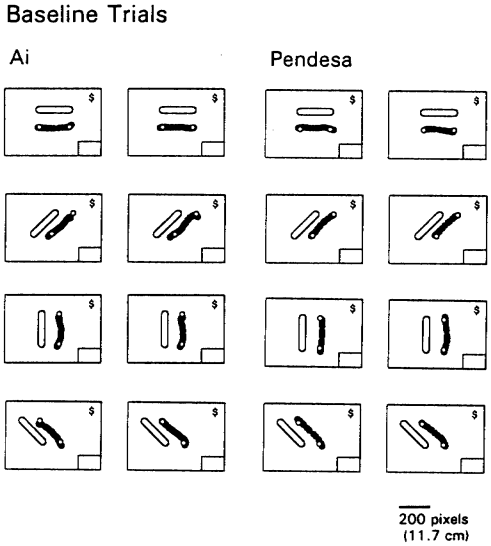


**Figure 2.** Examples of drawing on individual trials from baseline training. Each frame shows drawing for one trial. The model bar is indicated in outline to avoid confusion with the drawn trace, which appears in black; for the subjects, the model was solid blue. The two guide dots are shown here to indicate the precision of drawing even though they were actually covered by the drawn trace. The guide dots are shown larger than they appeared on the screen. The subjects connected the two dots with a sweeping movement that left a trace on the monitor and then pressed the trial-termination key, as described in Figure 1. Reinforcement is marked by a $ sign in the upper right-hand corner; this sign did not appear on the monitor.

### *Results*

*Baseline training*. Examples of individual trials showing the precision and reliability of drawing are presented in Figure 2. The model is shown in outline to avoid confusion between the model and the drawn trace. The guide dots were commonly covered by ink after drawing but are shown here to indicate their location and the precision of drawing. Reinforced trials are marked ($). The two guide dots controlled drawing because both subjects aimed at the startdot, moved the finger over the screen surface, and then lifted the finger when it came to the stopdot. Table 1 shows the average length, angle, variability, and percentage of trials reinforced for each trial type for each subject. The average length of the drawn trace was within 10 pixels of the distance between the guide dots, and the average angle was within 3° of the angle formed by an imaginary line connecting the two guide dots. The accuracy of drawing was close to 90% (reinforced trials) for both subjects. On unreinforced trials, the subjects typically drew a trace where either the length

**Table 1.** Baseline data for Experiment 1: The average length (*SD*), angle (*SD*), variability (*SD*), and percentage of reinforced trials for each trial type, indicated by angle of orientation of the two guide dots

| Orientation | Length (*SD*) (pixels) | Angle (*SD*) | Variability (*SD*) (pixels) | % reinforced trials |
|---|---|---|---|---|
| *Ai* | | | | |
| 0° | 207 (22) | −2° (9°) | 10 (7) | 83 |
| 45° | 195 (28) | 44° (7°) | 6 (7) | 92 |
| 90° | 176 (22) | 88° (5°) | 7 (6) | 96 |
| 135° | 189 (20) | 136° (7°) | 6 (5) | 88 |
| *Pendesa* | | | | |
| 0° | 202 (18) | 1° (4°) | 5 (5) | 91 |
| 45° | 196 (16) | 43° (6°) | 4 (3) | 89 |
| 90° | 202 (15) | 89° (5°) | 5 (4) | 92 |
| 135° | 194 (19) | 134° (6°) | 6 (4) | 93 |

Data are from two baseline sessions preceding probe sessions and from the baseline trials during test sessions. Criteria for reinforcement are described in the Appendix.
For Ai, 11 trials were excluded from analysis because she drew too fast thereby yielding too few (<8) touchpoints for analysis; similarly, 9 such trials were excluded from analysis for Pendesa.

or the angle was slightly outside the reinforcement criterion.

*First probe tests for model control.* Figure 3 presents the subjects' drawing on all probe trials type I (with the stopdot missing). For Ai, the model did not reliably guide drawing on probe trials. Pendesa drew a trace on all probe trials that appropriately followed the angle of the model, but the trace length was shorter than the model on all trials. The average trace length was 136, 130, 121, and 106 pixels (cf., 200 pixels for the model), and the average trace angle was 12°, 53°, 79°, and 114° for the 0°, 45°, 90°, and 135° displays, respectively. Pendesa therefore showed some evidence that the model could guide the angular component of drawing when the stopdot was missing from the screen on probe trials.

All probe trials type II with the startdot missing are presented in the top display of Figure 4. Ai connected the stopdot to the model on two trials, and on only one trial did she draw a trace that was roughly parallel to the model. On all trials, Pendesa merely touched the single guide dot. For both subjects, the model therefore did not guide drawing when the startdot was missing. The bottom display of Figure 4 shows all probe trials type III, with both guide dots missing. Ai drew something on each trial with the trace extending into the model area on seven trials; only one trial with a 90° display showed evidence of a trace parallel to the model. Pendesa marked the model on two trials and did not draw at all on four trials; she merely pressed the trial-termination key on such trials.

### Discussion

The results indicate that the method of presenting a model next to the two guide dots is not a very effective method of teaching guidance by the model. The subjects were drawing a trace parallel to and of the same length as the model when both guide dots were present on baseline trials. Because both subjects could draw an identical trace when only the two guide dots appeared on the screen (Iversen & Matsuzawa, 1996), the model was not a necessary stimulus for the correct connection of the two guide dots. However, the model might nonetheless have acquired some control by being spatially contiguous and aligned with the

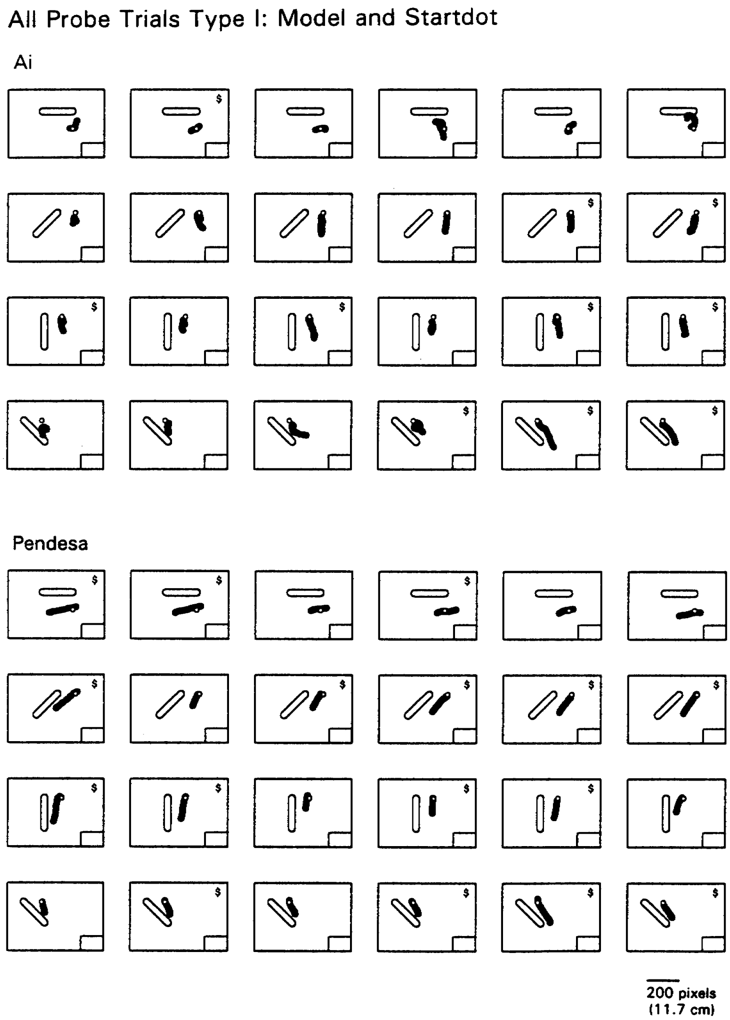


**Figure 3.** All probe trials from probe test type I are presented for Ai and Pendesa. The model and the startdot appeared on the monitor on each probe trial. Probe trials were mixed with baseline trials showing the model and both guide dots. (For additional information on the display see the caption to Figure 2.)

guide dots. When one or both guide dots were removed, the drawing behavior deteriorated for both subjects. Only one subject (Pendesa) drew a trace of a roughly correct angle when the stopdot was removed for probe trial type I but the trace was considerably shorter than the model on all trials.

The data indicate that even when the model may control the angular component of drawing it may not control cessation of drawing. Why the angular component of the model controlled drawing without the stopdot for Pendesa but not for Ai was not clear to us. Both subjects had received exactly the same training (Iversen & Matsuzawa, 1996). On probe trials without the startdot, Pendesa did not draw much at all. Ai drew something on all probe trials, but there was no evidence that the model controlled drawing except that Ai marked the model when both guide dots were missing.

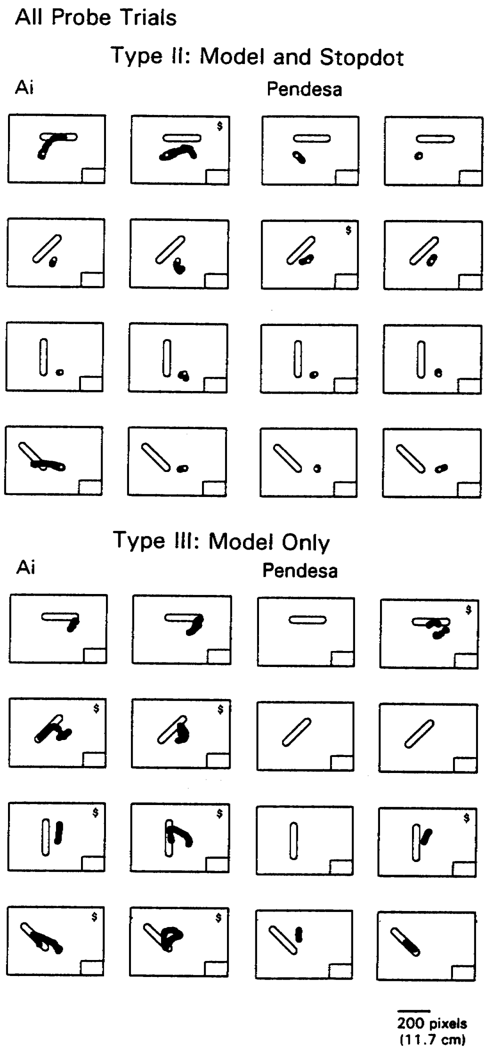


**Figure 4.** *Top*: All probe trials from probe test type II for Ai and Pendesa. The model and the stopdot appeared on the monitor on each probe trial. *Bottom*: All probe trials from probe test type III for Ai and Pendesa. Only the model appeared on the monitor on each probe trial. In both tests, probe trials were mixed with baseline trials that showed the model and both guide dots. (For additional information on the display see the caption to Figure 2.)

## Experiment 2

Because Ai did not show reliable model control, we attempted to teach her model-guided drawing by breaking the task into simpler components, based on principles of stimulus fading (e.g., Cooper, Heron, & Heward, 1987; Grant & Evans, 1994). The rationale of the fading method is that one stimulus may take over the control previously engendered by another stimulus that is gradually removed. Because our method is new and exploratory, details of the procedure are presented along with the results. Table 2 presents an outline of the procedure and the number of sessions of each step, as well as the average trace length and angle whenever appropriate.

### *Method and results*

Only Ai was used in Experiment 2. The apparatus was the same as in Experiment 1. For specific stimulus locations see "Exact stimulus descriptions" in the Appendix.

*Phase 1: Fading out stopdot control.* Initially, only two model orientations, 0° and 90°, were used. The model length was 200 pixels, as for Experiment 1. First, both guide dots were presented and a 1-pixel wide blue prompt line extended from the end of the model to the 10-pixel diameter stopdot; the distance between the stopdot and the end of the model was 120 pixels. After one session the stopdot was reduced to 5 pixels in diameter and thereafter removed. Over the next nine sessions the prompt line was gradually shortened in steps of 10 pixels for each session, leaving a gap from the end of the model to the prompt line, which gradually widened. Figure 5 shows four fading steps of removing the stopdot and the prompt line. Next, when the prompt line was only 10 pixels long, it was reduced in size to a barely visible 1-pixel blue point over six sessions (the size changes were 10, 8, 6, 4, 2, and 1 pixel). Then we tested the extent of model control by removing the 1-pixel stopdot on all trials in two sessions that alternated with a session with the 1-pixel stopdot. Each session had 40 trials with automated reinforcement criteria of a trace length of 200 ± 40 pixels, an angle of ±15°, and

**Table 2.** Procedural steps for Ai in Experiment 2

| | | | Trace length (pixels) | | | | Trace angle | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Procedure | Models | Session | 0° | 45° | 90° | 135° | 0° | 45° | 90° | 135° |
| *Phase 1: Fading out stopdot control* | | | | | | | | | | |
| Fade line from model end to stopdot and stopdot size | 0°, 90° | 1–15[a] | 248 (32) | – | 187 (28) | – | 1° (5°) | – | 88° (4°) | – |
| *Test*, no stopdot | 0°, 90° | 16 | 272 (27) | – | 148 (36)[b] | – | 1° (3°) | – | 86° (9°)[b] | – |
| 1-pixel stopdot | 0°, 90° | 17 | 242 (28) | – | 201 (19) | – | 3° (4°) | – | 89° (3°) | – |
| *Test*, no stopdot | 0°, 90° | 18 | 237 (29) | – | 190 (28) | – | 2° (3°) | – | 95° (7°) | – |
| *Test*, no stopdot | 0°, 45°, 90°, 135° | 19 | 216 (38) | 182 (38) | 154 (37) | 235 (62) | –3° (7°) | 112° (13°) | 112° (7°) | 138° (8°) |
| Fade stopdot | 45°, 135° | 20–22 | – | 194 (29) | – | 224 (33) | – | 44° (5°) | – | 137° (6°) |
| 1-pixel stopdot | 0°, 45°, 90°, 135° | 23 | 235 (36) | 192 (16) | 181 (32) | 221 (28) | 2° (4°) | 40° (4°) | 95° (11°) | 143° (5°) |
| *Test*, no stopdot | 0°, 45°, 90°, 135° | 24 | 240 (58) | 205 (15) | 162 (32) | 221 (49) | 0° (2°) | 53° (13°) | 118° (18°) | 136° (17°) |
| *Test*, no model, only startdot | 0°, 45°, 90°, 135° | 25[c] | See Figure 8 | | | | | | | |
| *Phase 2: New stimulus locations* | | | | | | | | | | |
| Model and both dots | 0°, 90° | 26 | See Figure 9 | | | | | | | |
| No model, both dots | 0° | 27 | 210 (28) | – | – | – | 1° (5°) | – | – | – |
| Model and both dots | 0° | 28 | See Figure 10 | | | | | | | |
| Model and both dots | 0° | 29–32[d] | 210 (31) | – | – | – | 2° (4°)[c] | – | – | – |
| Model and 1-pixel stopdot | 0°, 45°, 90°, 135° | 33 | 176 (28) | 195 (10) | 185 (32) | 196 (34) | 4° (4°) | 44° (9°) | 94° (9°) | 143° (4°) |
| *Test*, no stopdot | 0°, 45°, 90°, 135° | 34 | 166 (25) | 149 (34) | 137 (27) | 197 (52) | 2° (6°) | 44° (9°) | 102° (25°) | 153° (6°) |

Each session had 40 trials with an equal number of each trial type. Average trace length (*SD*) and average angle (*SD*) are shown for each model type for selected sessions or blocks of sessions.
[a] Data are from session 15 only.
[b] Four trials were excluded from analysis because extreme variability prevented a linear analysis.
[c] This session had only eight trials, two of each orientation (see text).
[d] Data are from session 32 only.

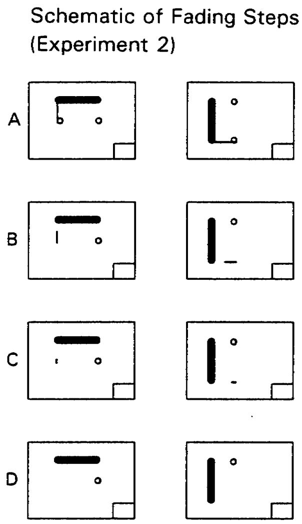


**Figure 5.** Schematic diagram of the method of fading used in Experiment 2. A: First, a prompt line extended from the end of the model to the stopdot. B–C: Over 15 sessions, a gap placed between the end of the model and the prompt line was gradually widened until only a 1-pixel dot appeared as the stopdot. D: In test sessions, the 1-pixel stopdot was removed.

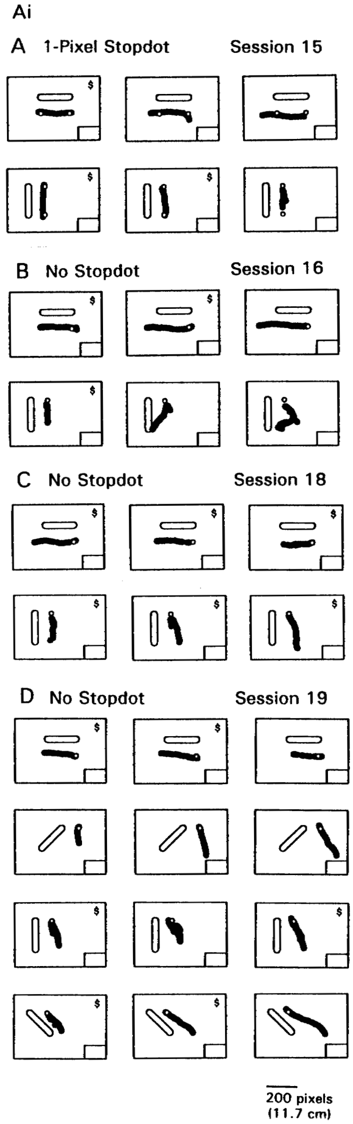


**Figure 6.** Drawing on selected individual trials from session 15, showing the 0° and 90° models and both guide dots (block A), and from sessions 16 and 18, showing the models and the startdot only (blocks B and C). The stopdot was only 1 pixel in session 15, which is too small to illustrate; hence, the stopdot is indicated at the same size as the startdot. Block D shows individual trials from session 19, which presented all four models and the startdot only. (For additional information on the display see the caption to Figure 2.)

variability less than 10 pixels (see "Reinforcement criteria" in the Appendix).

Examples of individual trials from the last session of fading with the 1-pixel stopdot (session 15) appear in block A in Figure 6. Because a 1-pixel dot is too small to show in the figure, the stopdot is indicated at the same size as the startdot. Ai clearly drew a trace parallel to the model on all trials (average data appear in Table 2). The traces extended beyond the stopdot on 14 of the 20 0°-model trials but ended at or near the stopdot on all 90°-model trials. Examples of trials from the first session without the stopdot (session 16) are shown in block B. For the 0° model, the drawn trace was parallel to but longer than the model on all trials. For the 90° model, Ai drew a vertical trace that was nearly as long as the model on

14 of the 20 trials (such as the first trial for the 90° model in block B in Figure 6); however, Ai connected the startdot to the end of the model on three trials, and the trace became very irregular on three trials, as represented by the second and third trial in block B.

When the 1-pixel stopdot was replaced on all trials in session 17, Ai again connected the two dots for both model orientations, as she had done in the similar session 15 (see Table 2). When the stopdot was removed the second time in session 18 (block C in Figure 6), Ai drew parallel to but beyond the model on eight of the 20 trials with the 0°-model orientation. On 90°-model trials, the variability of the trace again increased but not as much as for the similar session 16, and Ai drew a trace that was roughly parallel to the model on all trials although the trace slanted slightly toward the trial-termination key without reaching it on 13 of the 20 trials. Thus, the two models clearly controlled different drawing when the stopdot was removed.

To examine whether model control would generalize to the two untrained models (i.e., 45° and 135°) after training with the 0° and the 90° models, we next presented all four model orientations without the stopdot in session 19 (each trial type was presented in 10 trials). Block D in Figure 6 presents the first three trials of each model orientation. For the 45° model, Ai drew a short vertical trace on three trials and drew toward the trial-termination key on the remaining seven trials. For the 135° model, Ai drew a line parallel to the model but on four of the 10 trials the trace extended beyond the model toward the trial-termination key. Thus, on 17 of the 20 trials with the 45° or 135° model, Ai drew a line that extended from the startdot toward the trial-termination key. Drawing on 45°- and 90°-model trials could not be distinguished, as also indicated by the averages presented in Table 2. The data, therefore, indicate that model control established previously for the 0° and 90° models did not generalize to the untrained 45° and 135° models. For those models, the trial-termination key also exerted control over drawing; hence, drawing in the "correct" angle for the 135° model could result from either control by the trial-termination key or control by the model. Ai drew a line parallel to the 0° model as in previous sessions (i.e., blocks B and C in Figure 6). However, the 90°-model lost some control over drawing as the trace became too short or slanted toward the trial-termination key without reaching it (i.e., the average angle was 112°). Thus, mixing the untrained 45° and 135° models with the trained 0° and 90° models did not lead to transfer of model control to the 45° and 135° models but instead resulted in loss of control by the 90° model.

In an attempt to establish control on trials with the 45° and the 135° models using the fading method, Ai had three 40-trial sessions with only these two models. The stopdot was reduced in size from 10 to 5 and then to 1 pixel over the three sessions. Next, session 23 presented all four models and a 1-pixel stopdot. Block A in Figure 7 shows the first three trials of each model from this session. Ai drew traces parallel to and of the same length as the model (see Table 2). To assess control by all four models, the stopdot was removed in session 24. Selected individual trials are shown in block B in Figure 7. The fading method apparently improved model control because Ai now drew a trace parallel to the model on seven of the 10 45°-model trials and on all 10 of the 135° model trials. However, on one 45° trial, two 90° trials, and two 135° trials Ai still drew from the startdot toward the trial-termination key. Even though model control was not established perfectly, the average angles of Ai's traces were now more clearly distinguished and approximated the angle of the model. Thus, for session 24 the average angles were 0°, 53°, 118° and 136° for the 0°, 45°, 90°, and 135° models, respectively.

For the test sessions with the model and startdot only (i.e., sessions 16, 18, 19, and 24), Ai always drew a line parallel to the 0° model, but the control over the trace angle was less clear for the remaining models. Wondering about this difference in control led us to examine the stimuli on the monitor carefully. Column A in Figure 8 shows what the screen looked like before drawing began for each

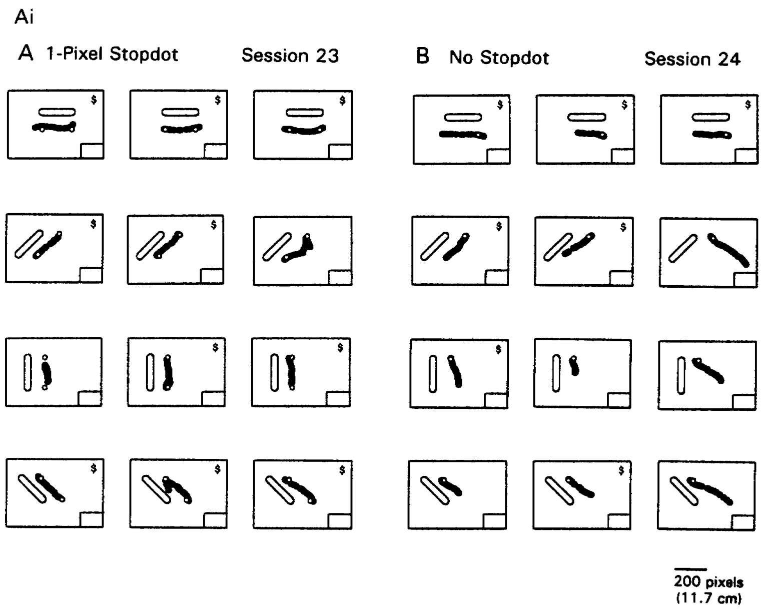


**Figure 7.** Selected individual trials showing drawing for all four model orientations with both guide dots in session 23 (block A) and with the startdot only in session 24 (block B). The stopdot was only 1 pixel in block A and is indicated at the same size as the startdot. (For additional information on the display see the caption to Figure 2.)

model orientation on trials with the startdot only. Notice how the startdot for the 0° model has a considerably different location on the screen compared with the startdot for the other models. To examine the possibility that the startdot location for the 0° model guided drawing independently of the model, we presented two trials of each model orientation but without actually showing the model. In one short session, the screen merely displayed the startdot and the trial-termination key, as shown in column B (Figure 8); no reinforcement was given on any of these eight trials (session 25). Columns C and D in Figure 8 present the drawing on these trials. On the two trials corresponding to the 0° model, Ai drew a horizontal trace (213 and 253 pixels long), as she had done previously on trials with the 0° model. She drew inconsistently on the remaining trials. Ai's drawing on these few test trials seems to indicate that the relative location of the startdot guided the angular component of drawing on 0°-model trials (i.e., the model itself probably did not guide drawing).

*Phase 2: New stimulus locations.* We reasoned that model guidance might be enhanced if the control over the angular component of drawing by the relative location of the startdot could be reduced or eliminated. Instead of having four different startdot locations as before, we rearranged the stimuli on the monitor so that the 0° model and the 45° model shared one startdot location, and the 90° and 135° models shared a different startdot location. Column A in Figure 9 shows the new model and startdot locations. Notice that the startdot now is placed above the model for the 0° trials.

To determine whether the startdot would in fact control drawing when located above the 0° model, session 26 presented the 0° and the 90° models with the startdot at its usual size of 10 pixels and a stopdot 5 pixels in diameter. On trials with the 90° model, Ai correctly connected the dots on 19 of the 20 trials, as shown in selected individual trials in column B in Figure 9 (on one trial Ai drew irregularly). However, Ai did not connect the guide dots on any single 0°-model trial, as exemplified in

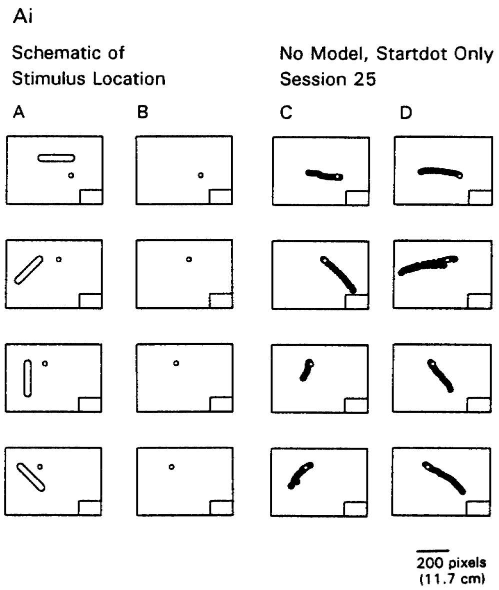


**Figure 8.** Column A shows a schematic diagram of the specific stimulus locations for the four models, and column B specifically shows the startdots only. Notice how the startdot is located in the lower right quadrant for the 0° model while the startdots are much higher on the screen for the remaining models. Columns C and D present individual trials from session 25, which presented eight trials with only the startdot. (For additional information on the display see the caption to Figure 2.)

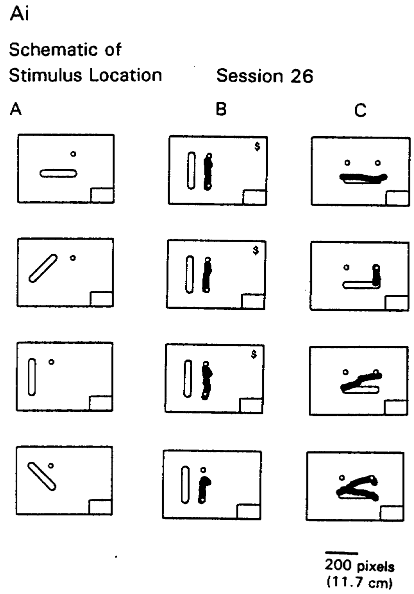


**Figure 9.** Column A shows a schematic diagram of the screen at trial start after the stimuli were rearranged to facilitate control by the model. The logic of the rearrangement was to reduce control by the startdot locations by having the 0° and 45° models share a startdot at one location and having the 90° and the 135° models share a startdot at a different location. Columns B and C show drawing on selected trials from session 26, which presented the 0° and the 90° models with both guide dots. (For additional information on the display see the caption to Figure 2.)

column C. Instead, she drew along the model or connected the startdot to the model.

To make sure that Ai could connect the guide dots in their new position regardless of the model, session 27 presented just the two guide dots in the 0° orientation without showing the model. After a few trials Ai correctly connected the two guide dots on all trials. Then session 28 reintroduced the 0° model. Figure 10 presents all individual trials of this session to illustrate the strong influence of previous stimulus control on drawing in a new situation (the order of trials is indicated by numbers). Because we had anticipated that the new stimulus locations would control poorly, we used manual reinforcement in this session to encourage continued drawing; reinforcement was presented on the first two trials and then only when Ai connected the guide dots without marking the model. On the first eight trials, Ai began by connecting the guide dots and then drew over the model before she pressed the trial-termination key. Notice that the model now was located approximately where Ai previously had drawn when the startdot was under the model. On the ninth trial Ai for the first time connected the guide dots without marking the model. Ai continued to draw on top of the model on most trials. She also often retraced over the trace that she had made herself to

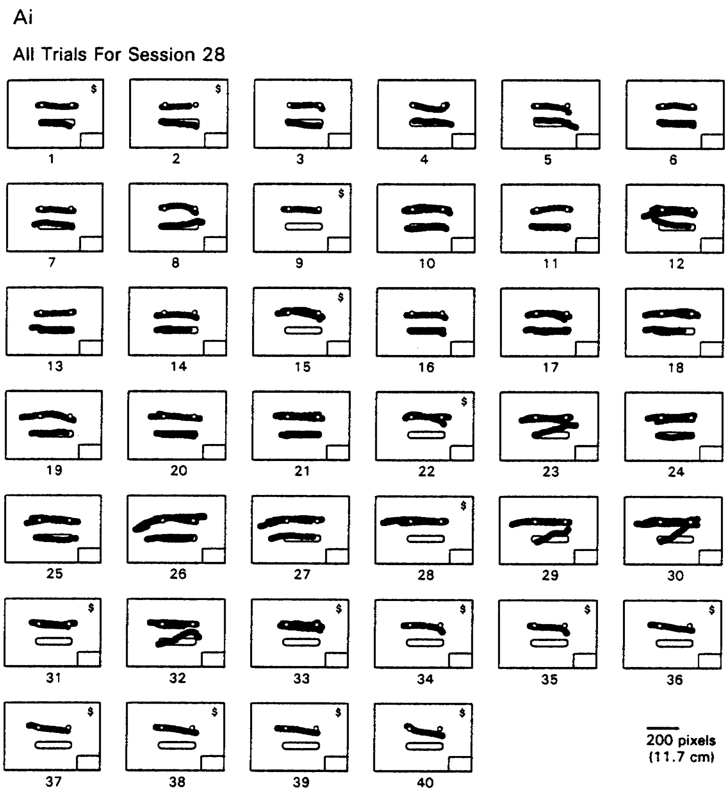


**Figure 10.** Drawing on all trials in session 28 with the 0° model and the guide dots located above the model. Reinforcement was given manually on the first two trials and later only when Ai connected the dots and refrained from marking the model. Numbers refer to the order of the trials within the session. (For additional information on the display see the caption to Figure 2.)

connect (and cover) the two guide dots (e.g., trial 12). Trials without tracing over the model gradually became more frequent even though Ai continued to retrace the trace she had just made to connect the two guide dots. Only on the last seven trials did Ai consistently draw a single trace that connected the guide dots. The data show that Ai could easily learn to connect the two guide dots in their new location, but many trials without reinforcement were required before Ai ceased to draw in the previously "correct" location. These data confirm the trend seen in the test session with only the startdot (i.e., session 25, Figure 8). For the 0° model used in previous sessions, Ai had apparently learned to draw a horizontal trace at a specific location guided by only the startdot and not by the model itself. Four additional sessions (29–32) with only the 0° model and both guide dots further established drawing above and not on the model (see averages in Table 2).

Session 33 then presented all four model orientations with the startdot and a 1-pixel stopdot. Session 34 also presented the four model orientations but the stopdot was removed. Figure 11 presents selected individual trials from these two sessions. With both guide dots (block A), Ai drew a line parallel to the model on all trials (see averages in Table 2).

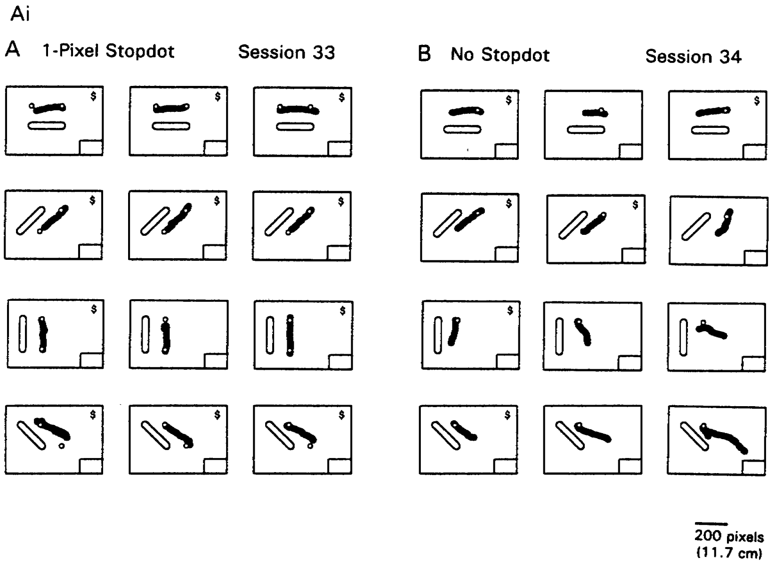


**Figure 11.** Block A shows drawing on selected trials from session 33 with all four models and both guide dots. Block B shows selected trials from session 34 with all four models and the startdot only. (For additional information on the display see the caption to Figure 2.)

Because Ai drew to a point above the stopdot on seven of the 10 135°-model trials, the average slant of the trace was 143° and thus exceeded that of the model. When the stopdot was removed in session 34, Ai drew a trace parallel to the model on nine 0°-model trials and on all 45°-model trials. For the 90° model, Ai drew a vertical trace on seven of the 10 trials but drew three traces pointing toward but not reaching the trial-termination key (one of these traces was nearly horizontal and drawn from left to right, as shown in the third trial for this model in block B, Figure 11). For the 135° model, Ai drew a line from the startdot to a point considerably higher than where the stopdot had been located on eight of the 10 trials, and on two trials she drew all the way to the trial-termination key, as shown in the last trial for this model in Figure 11. Thus, on 19 of the 20 0°- and 45°-model trials, the model now controlled drawing a trace parallel to it. Because these two trial types shared the same startdot, the model orientations with that startdot could now be said to control the angle of drawing. However, for the 90°- and 135°-model trials, which also shared a startdot, model control was less clear, with some overlap in the trace angle.

### *Discussion*

The results demonstrate that the smallest graphical unit on the monitor – the 1-pixel stopdot – was in fact exerting control over Ai's drawing. On trials that featured the stopdot, Ai commonly ceased to draw when her finger reached the stopdot, but on trials without the stopdot she either drew past that location (for the 0° model) or drew with variability for the remaining models. Yet, during the procedure where the stopdot was faded away, Ai's drawing on trials without the stopdot improved considerably compared with the complete lack of model control evidenced on probe trials in Experiment 1. Interestingly, in phase 1 in Experiment 2, the endpoint of the model exerted some degree of control that was not intended. On some trials for the 90° model, Ai thus connected the startdot to the end of the model when the stopdot was missing. This reveals that Ai must have been looking at the model and that it was gaining some degree of control over drawing. Even though fading out the control by the stopdot helped to establish some degree of model control, this did not generalize beyond the trained models. The specific locations of the startdot, the end of the model, and the trial-termination key began to control drawing on trials without the stopdot. In sum, teaching by stimulus fading made the model guide drawing on many but not all trials. The data reveal that Ai was able to draw a line parallel to the model when the stopdot was removed. Ai's drawing now roughly resembled Pendesa's drawing on probe trials type I in Experiment 1.

## Experiment 3

Experiment 3 attempted to improve the behavior of drawing a line parallel to a model for both subjects. In Experiment 1, Pendesa had shown some evidence that she was able to draw correctly on many probe trials showing the model and the startdot, but the trace she drew was almost always too short. After having been taught model control in Experiment 2, Ai was also able to draw a line parallel to the model, but for her, too, the trace was commonly shorter than the model. Ai's drawing in Experiment 2 revealed that the relative location of the startdot exerted control over the orientation of drawing (at least for the 0° model). The stimulus display used last in Experiment 2, where the 0° and the 45° models shared the same startdot and the 90° and the 135° models shared a different startdot, was used again in Experiment 3. To further reduce control over the orientation of drawing by the startdot location, we next eliminated the 0° model and arranged for the remaining models to share the same startdot. In addition, Experiment 3 introduced a "multiple-stroke contingency," whereby the subject could add a second stroke to the display on the monitor after the first trial-termination response on trials where the first stroke was too short but parallel to the model.

### Method

*Subjects and apparatus*. The subjects and apparatus were the same as for Experiment 1. Immediately before Experiment 3 began, both subjects had sessions (10 for Ai and 27 for Pendesa) that displayed only the guide dots on the monitor; the task was to connect the dots. Automatic reinforcement criteria were used for both subjects. The purpose of this procedure was to maintain drawing behavior and the daily training routine while data were analyzed and programs prepared for further training.

*Phase 1: Four models and two startdot locations*. The stimulus display was as in phase 2 in Experiment 2. Thus, the 0° model and the 45° model shared the same startdot location, and the 90° model and the 135° model shared a different startdot location. In addition, the startdot appeared above the model for trials with a horizontal display. For precise locations of the stimuli see "Exact stimulus descriptions" in the Appendix.

Because the locations of model and startdot were reversed compared with Experiment 1 for the 0° model, one 48-trial session with the new locations of model and both guide dots was scheduled for Pendesa to determine how the new stimulus locations controlled drawing. Pendesa correctly connected the guide dots in this session on all trial types (this is in contrast to Ai, for whom the reversal of the location of startdot and model in Experiment 2 caused her to draw on the model – see Figure 9). After this session, probe trials showing the model and only the startdot were mixed with baseline trials showing the model and both guide dots. Eight sessions each had 48 trials, of which 16 were probe trials with four of each model orientation. For baseline trials, the reinforcement criteria were 200 ± 40 pixels for length, ±10° for angle, and 10 pixels for variability. On probe trials the criteria were widened to increase the likelihood that drawing would be reinforced, to 200 ± 50 pixels for length, ±15° for angle, and unchanged 10 pixels for variability.

For Ai, all trials in a session featured the model and the startdot as in phase 2 in Experiment 2. Each of eight sessions had 48 trials with 12 trials of each model orientation. The automatic criteria for reinforcement were 200 ± 50 pixels for length, ±15° for angle, and 10 pixels for variability.

*Phase 2: Three models and one startdot location*. The 0° model was no longer presented,

**Table 3.** Average (*SD*) trace length and angle for both subjects in Experiment 3

| | | | Trace length (pixels) | | | | Trace angle | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Procedure | Models | Sessions | 0° | 45° | 90° | 135° | 0° | 45° | 90° | 135° |
| *Phase 1: Four models and two startdot locations* | | | | | | | | | | |
| *Pendesa* | | | | | | | | | | |
| Baseline trials | 0°, 45°, 90°, 135° | 8 | 204 (24) | 188 (24) | 196 (20) | 197 (19) | –3° (4°) | 46° (4°) | 87° (3°) | 133° (3°) |
| Probe trials | 0°, 45°, 90°, 135° | 8 | 122 (36) | 139 (48) | 143 (35) | 168 (36) | 11° (8°) | 45° (15°) | 82° (19°) | 126° (8°) |
| *Ai* | | | | | | | | | | |
| All trials | 0°, 45°, 90°, 135° | 8 | 247 (29) | 161 (39) | 124 (44) | 156 (54) | 2° (6°) | 49° (22°) | 98° (20°) | 133° (22°) |
| *Phase 2: Three models and one startdot location* | | | | | | | | | | |
| *Pendesa* | | | | | | | | | | |
| All trials | – , 45°, 90°, 135° | 7 | – | 186 (41) | 191 (51) | 202 (51) | – | 60° (14°) | 81° (20°) | 130° (13°) |
| *Ai* | | | | | | | | | | |
| All trials | – , 45°, 90°, 135° | 16[a] | – | 182 (29) | 164 (30) | 181 (42) | – | 50° (12°) | 83° (13°) | 121° (7°) |

Subjects were drawing a trace parallel to a model beginning from a startdot. Drawing was reinforced according to set criteria (see procedure).
[a] Data are based on the last 8 sessions.

and the stimuli on the screen were relocated slightly so that the remaining models (i.e., 45°, 90°, and 135°) shared the same startdot location (see "Exact stimulus descriptions" in the Appendix). The purpose of this modification was to determine whether model control could be improved if control by the startdot location was removed. Because the startdot now had the same location on all trials, only the model could guide drawing in the correct direction.

In previous sessions, both subjects customarily drew a trace that was shorter than the model and then pressed the trial-termination key, which ended the trial. In phase 2, the procedure was changed to a multiple-stroke contingency. As before, the trial ended in reinforcement if the drawn trace satisfied all three criteria for reinforcement when the subject pressed the trial-termination key. However, if the drawn trace had an appropriate angle and variability but was shorter than the length criterion for reinforcement then the trial did not end at the first trial-termination response. Instead, the model and the drawn trace remained on the monitor, and the subject could now add another stroke to the screen, to make the drawn trace longer. When the subject then made a second trial-termination response, the combined trace was evaluated again and the trial ended in reinforcement when all three criteria were met. Ai had 16 and Pendesa had seven 48-trial sessions (16 trials of each of the three model orientations); data are presented for the last eight sessions for Ai and for all seven sessions for Pendesa.

For both phases, sessions were often separated by one or two sessions featuring trials with the model and both guide dots or only the guide dots (no model was shown) appearing in one of the four orientations; except where noted, data are not presented for these sessions because both subjects correctly connected the two guide dots on all trials.

### *Results*

*Phase 1: Four models and two startdot locations*. Pendesa continued to draw a line parallel to the model on most probe trials. However, the trace length was commonly shorter than the model. Table 3 presents the angle and length averages. Figure 12 compares the length and angular component of the trace on each trial in a scatterplot of these two aspects of the drawing behavior. The *x*-axis presents the trace

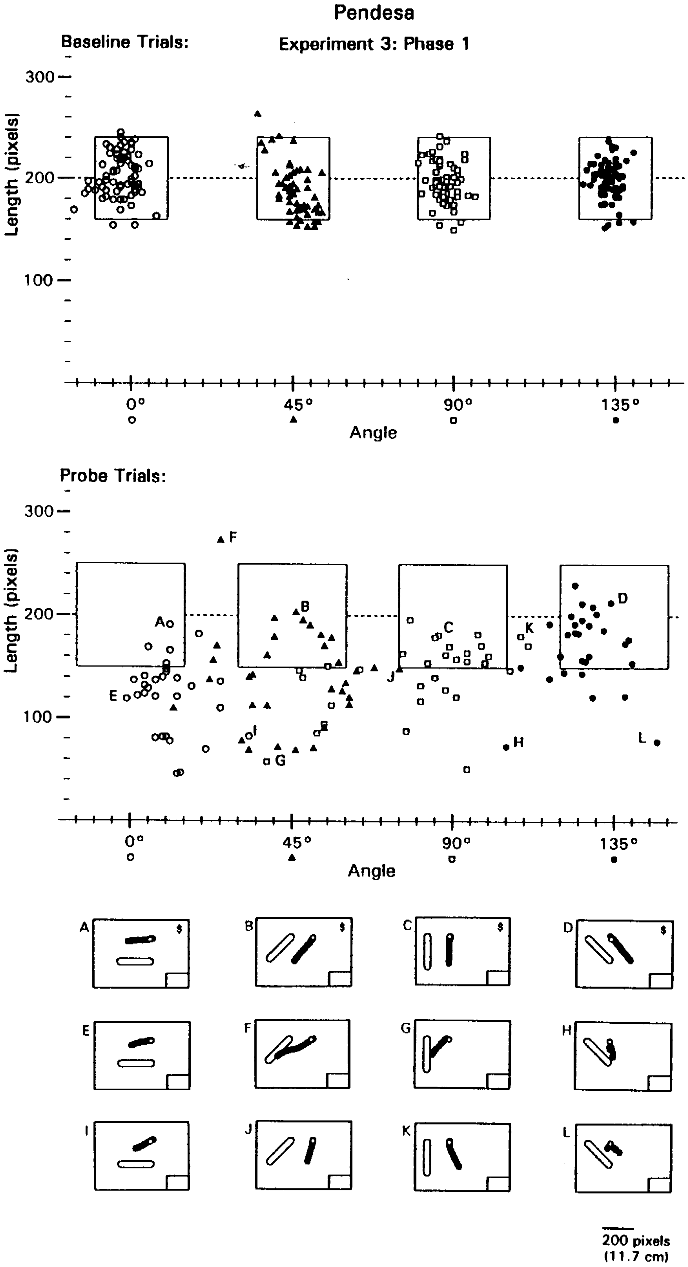


**Figure 12.** *Top and middle*: Pendesa's phase 1 data showing a comparison of the angle and length of each drawn trace for baseline trials (top) and probe trials (middle). Data are presented in a scatterplot. Data points are marked for each model orientation, as indicated under the *x*-axis. Boxes indicate the criteria for reinforcement during baseline trials of ±10° for angle and ±40 pixels for length and of ±15° and ±50 pixels for probe trials; data points inside an appropriate box thus represent reinforced trials. *Bottom*: Drawing on selected individual probe trials. Letters correspond to data points in the middle display; for example, the trace marked F has a length of 269 pixels and an angle of 24°. (For additional information on the display see the caption to Figure 2.)

angle and the y-axis shows the trace length. Thus, one data point shows these two dimensions of the trace for one trial. Data points are coded for model orientation. Boxes for each model represent the reinforcement criteria for both angle and length; hence, a data point falling inside the appropriate box indicates that *both* angle and length were within the reinforcement criteria on that trial. The data for all baseline trials in the upper display indicate that both angle and length matched the dot orientation presented on the monitor on the majority (91%) of the trials. Because the trace angles for the four model orientations are not overlapping, the angular component of drawing shows differentiation with respect to model orientation. The trace angle was within the reinforcement criterion of ±10° on all but four trials (all for the 0° display). The trace length was within the reinforcement criterion of ±40 pixels on all but 18 trials. Notice that traces with a length outside the length criterion mostly fell inside the angle criterion (i.e., the data points above or below a box).

The probe trial data for Pendesa are presented in the middle display of Figure 12; notice that the reinforcement criteria were wider on probe trials. Actual drawing on selected individual probe trials are presented in the lower display to help visualize the interaction between length and angle. For each model, three trials show one trace inside the reinforcement criteria (top row, i.e., A–D) and two traces at the outer fringes of the scatter for each model (second and third rows). Each trace is coded by a letter for identification as a data point in the scatterplot. According to this analysis 12%, 34%, 44%, and 63% trials fell inside the dual reinforcement criteria for length and angle for the 0°, 45°, 90°, and 135° models, respectively, yielding an overall percent "correct" (i.e., reinforced) probe trials of 38.3%. These data reveal that on some trials for each model Pendesa certainly was able to draw a trace parallel to and of the same length as the model (for examples see top row of selected trials). The data for the 135° model were particularly clear, with only three to six probe trials deviating considerably from the reinforcement criteria. The majority of the remaining trials featured traces that were of an appropriate angle but too short. On a few trials Pendesa drew a trace toward the model or drew away from the model. The weakest control appeared for the 0° model, where Pendesa often drew a trace directed toward (but without reaching) the end of the model, which resulted in positive angles as large as 33°. The 90° model generated the most variability in the angular component of drawing, with angles from 39° to 112°.

In general, model control on probe trials was quite weak, as seen in the somewhat overlapping trace angles across model orientations. The four distributions are thus not as clearly differentiated as for baseline trials. However, non-neighboring distributions are not overlapping, suggesting that the model did control the angular component of the drawn trace to some extent. Thus, the percentage of trials with a "correct" angle (within the probe-trial reinforcement criterion of ±15°) were 81%, 69%, 69%, and 88% for the 0°, 45°, 90°, and 135° models, respectively. The percentage of trials with a "correct" length (within the reinforcement criterion of ±50 pixels) were 16%, 38%, 53%, and 69% for the 0°, 45°, 90°, and 135° models, respectively.

On sessions where both guide dots were presented on all trials, Ai correctly connected the dots and left a trace that was within the reinforcement criterion regarding length of 200 ± 40 pixels on 92% of the trials and within the reinforcement criterion regarding angle of ±10° on 89% of the trials. Hence, Ai still drew a near 200-pixel trace at the appropriate angle when both guide dots were presented, as she had done in Experiments 1 and 2.

The upper part of Figure 13 presents a scatterplot for Ai of the trace angle and the trace length for all trials in phase 1 where the model and only the startdot appeared on all trials (i.e., the method of mixing baseline trials and probe trials within a session was not used for Ai). The lower part presents individual traces to illustrate the interaction between trace angle and length. As for Figure 12, trials in the upper row present traces near the middle of each box, and trials in the next two rows

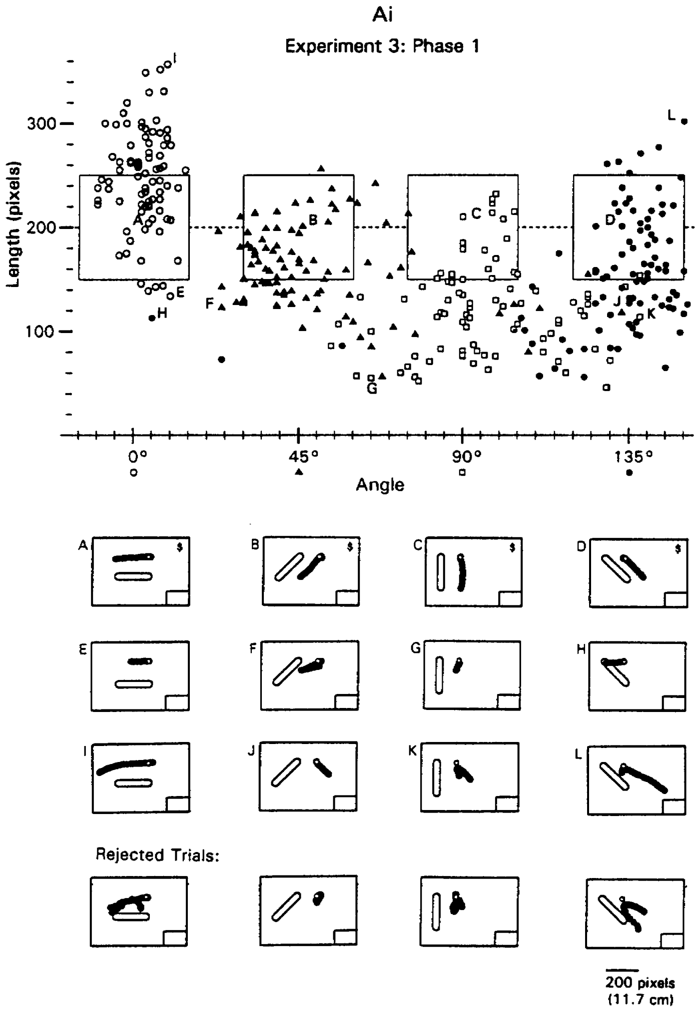


**Figure 13.** *Top*: Ai's phase 1 data showing a scatterplot comparison of the angle and length of each drawn trace (see caption for Figure 12). *Bottom*: Drawing on selected individual trials. Letters correspond to data points in the top display. The lowest row shows examples of trials that were rejected for analysis because of too few touchpoints, variability that prevented a linear analysis, or double traces (8% of the trials were rejected). (For additional information on the display see the caption to Figure 2.)

show traces with extreme deviation from the central tendency. The fourth row shows examples of trials that were rejected from analysis because they had too few touchpoints or because the trace could not be given a meaningful linear analysis, such as when two deviating traces were made on the same trial.

The data show that 24%, 40%, 44%, and 44% of the traces fell inside the reinforcement criteria for the 0°, 45°, 90°, and 135° models, respectively, yielding an overall percent "correct" (i.e., reinforced) trials of 37% for Ai. Traces in the top row of selected trials indicate that for each model Ai was certainly capable of drawing a trace that was as long as and parallel to the model. However, this drawing was not stable. For the 0° model, all traces were of the appropriate angle but about half were longer than the upper end of the length criterion. The 0° and 45° models shared the same startdot, and the trace angles for those two models did not overlap. However, 32% of the traces for the 45° model had an angle that fell outside the reinforcement criterion and overlapped with traces for both the 90° and the 135° model. The most extreme case was trial J, where the trace pointed toward the trial-termination key with an angle of 132° (but only five trials had angles above 90° for the 45° model). For the 90° model, the majority of the traces were shorter than the reinforcement criterion, and the trace angle overlapped with the reinforcement criterion for the 135° model. Last, for the 135° model, five traces exceeded the length criterion because they went toward the trial-termination key. An indication that model control was not clearly established for the 135° model was that Ai drew toward the model on three trials either horizontally or diagonally.

*Phase 2: Three models and one startdot location*. Figure 14 (top) displays the relationships between the angle and length of the drawn traces for all Pendesa's trials. The percentage of reinforced trials was 48%, 38%, and 71% for the 45°, 90°, and 135° models, respectively. In total, 52.3% of all traces were within the reinforcement criteria of 200 ± 50 pixels and ±15°. However, Pendesa also drew traces that overlapped with the angle criterion for one of the other models. For example, 19.8% of the trace angles for the 90° model were within 45° ± 15° and 6.5% of the trace angles were within 135° ± 15°. In total, for 12.9% of all trials, the trace was drawn in an angle that was appropriate for one of the other models. The average trace lengths improved compared with the averages for probe trials from phase 1, indicating that allowing Pendesa to correct a trace that was too short clearly increased the average length of the drawn trace and increased the percentage of correctly drawn traces.

Figure 14 (bottom) presents the relationships between the angle and length of the drawn traces for all Ai's trials. The percentage of reinforced trials was 76%, 64%, and 43% for the 45°, 90°, and 135° models, respectively. In total, 61% of all traces were within the reinforcement criteria of 200 ± 50 pixels and ±15°. Both average trace angles and average trace lengths improved compared with phase 1. An additional sign of improvement is the reduction in the standard deviations (see Table 3). As for Pendesa, removing the 0° model and allowing more than one stroke to occur on a single trial improved model control. For Ai, traces only rarely were directed toward the trial-termination key. Similarly, drawing toward the model occurred only sporadically.

To illustrate the extent of model control obtained with this teaching method, Figure 15 presents all trials for Ai from one session in phase 2 where model control was particularly well pronounced. Trials occurred in mixed order but are ordered sequentially here to ease comparison within and across models. Notice how the trace angles are clearly differentiated by the model orientation. Only the traces on the first two trials for the 45° model resemble traces for some of the 90°-model trials. Even though many trials went unreinforced because the trace fell outside of the angle or length criterion, the data indicate that Ai was capable of drawing a line parallel to the model on the majority of the trials.

For both subjects, the multiple-stroke contingency in phase 2 generated more effective drawing. Figure 16 shows how this contingency affected drawing, as illustrated by selected individual trials for Ai. Six trials of each model orientations show the first stroke, the second stroke if one occurred, and the cumulated trace. When a stroke was not reinforced because it was too short, the stimuli remained on the screen and Ai could supplement the drawing by adding a second stroke. On three trials for the 45° model, Ai thus added a second stroke that started roughly where the first ended. Notice how the model also guides the angle of the second stroke. A similar pattern is seen for the 90° and the 135° models. On one trial for the 45° model and on two trials for the 90° model, Ai did not make a second stroke and

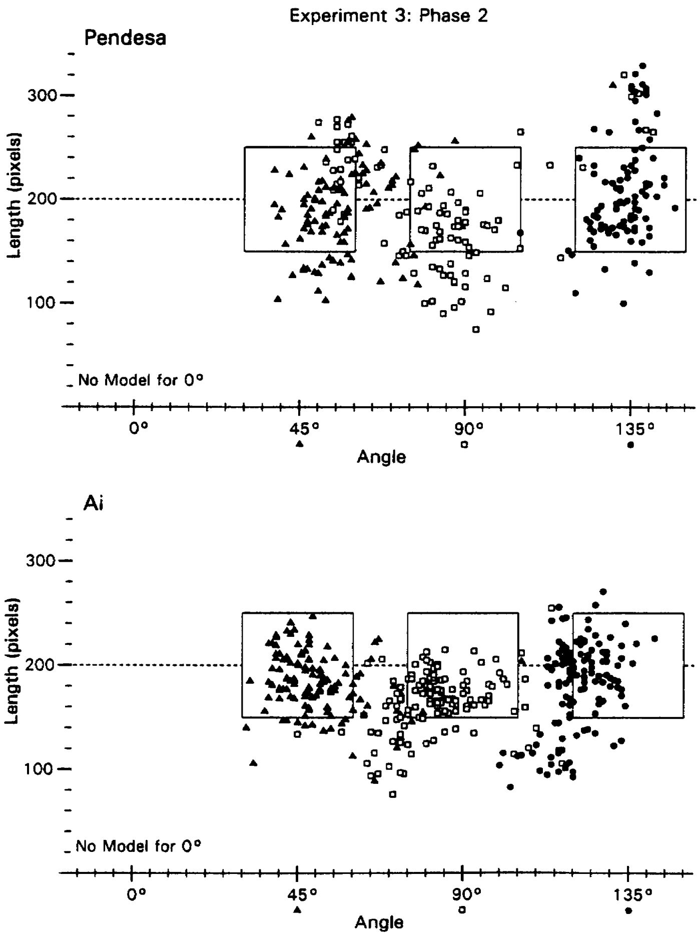


**Figure 14.** Phase 2 data showing a scatterplot comparison of the angle and length of each drawn trace with three models (45°, 90°, and 135°) for both subjects (see caption for Figure 12). All trials in a session displayed the model and the startdot only. For Pendesa 19 trials and for Ai four trials were rejected from analysis because of an extreme variability score that prevented a linear analysis.

instead pressed the trial-termination key a second time. For Ai, 60% of the trials had a second stroke and 78% of these strokes had the appropriate angle; 46% of the trials with a second stroke improved the cumulated trace enough to result in reinforcement. For Pendesa, 31% trials had a second stroke and 55% of these strokes had the appropriate angle; 25% of the second-stroke trials were reinforced.

### *Discussion*

The results for phase 1 indicate that the model exerted partial control over drawing. Both subjects clearly were able to draw a trace parallel to the model at an appropriate length. But the drawing was not consistent and tended toward a trace that was too short. For Ai, the angles of the drawn traces for the 0° and 45° models were clearly differentiated, indicating model

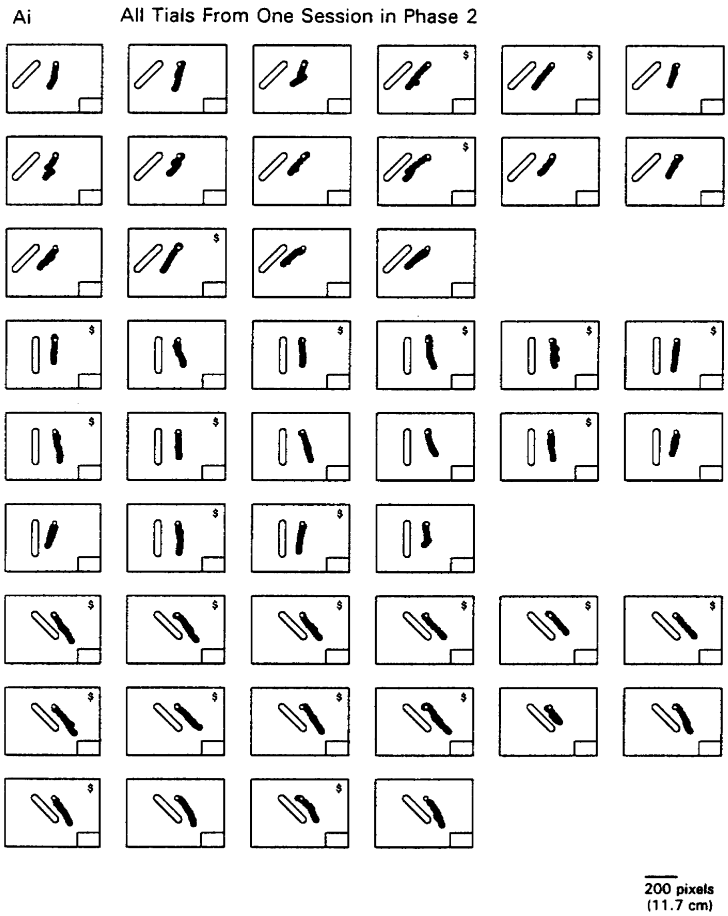


**Figure 15.** Ai's phase 2 data showing drawing on all 48 trials from one session. Trials are presented sequentially for each model with the first trial in the session on the left (trials occurred in mixed order during the session). (For additional information on the display see the caption to Figure 2.)

control because these two models had the same startdot location. The 90° and 135° models shared a different startdot location but trace angles overlapped for these two models. Both subjects also drew toward the trial-termination key on some trials or toward the model on other trials, revealing the competing sources of control over drawing.

In phase 2, removing the 0° model, having all models share the same startdot, and introducing the "multiple-stroke contingency" improved drawing for both subjects, but more so for Ai. Both subjects often added to or corrected a trace that was of an appropriate angle but too short. The average length of the trace improved with the change in method. However, the variability in length increased for Pendesa and decreased for Ai. Pendesa's longer traces resulted partly from connecting the startdot with the lower edge of the model or with the trial-termination key. Even though mistakes in drawing were fewer in phase 2 for both subjects, the unwanted sources of control over drawing exerted by the trial-termination

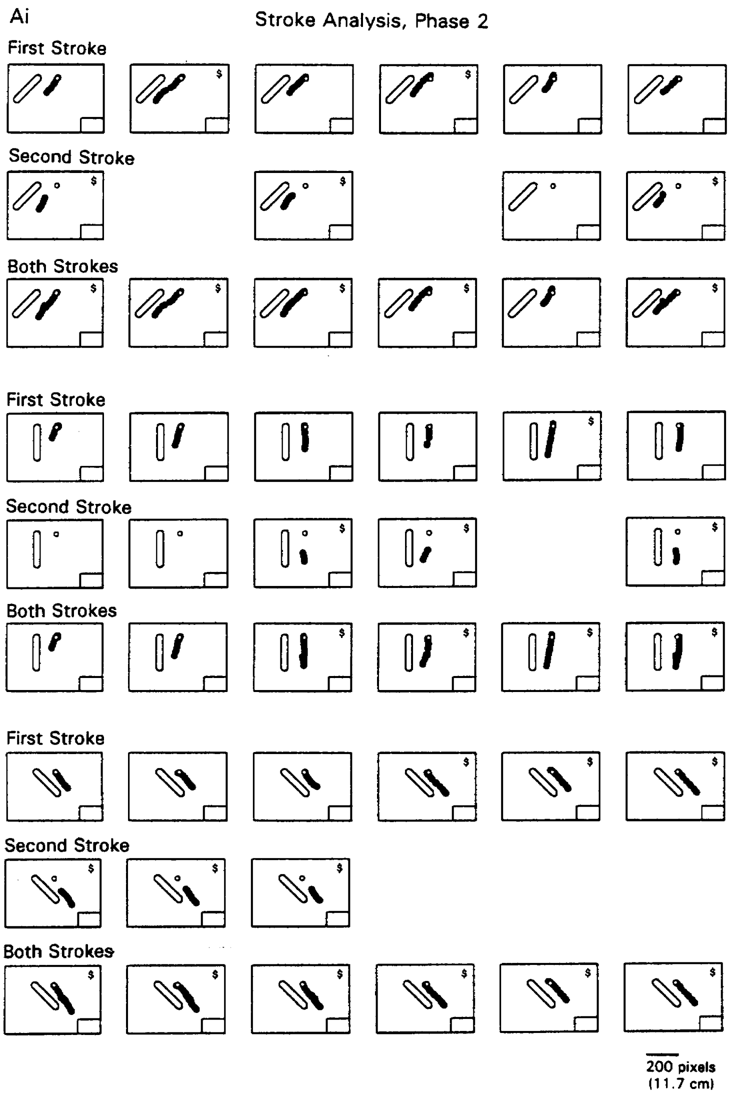


**Figure 16.** Ai's phase 2 data illustrating the multiple-stroke contingency. Drawing on six individual trials are selected for each model orientation. Data show the first stroke, the second stroke if one occurred, and the cumulated trace. Thus, each trial reads from top to bottom. A stroke was defined as cessation of drawing followed by lifting the finger and drawing on a new location or followed by a trial-termination response. If the first stroke was reinforced there was no opportunity for a second stroke on that trial, hence the blanks under reinforced first strokes. If the first stroke had a correct angle but was too short then the trial-termination response did not end the trial and a second stroke was allowed. The combined stroke was analyzed by the reinforcement criteria of 200 ± 50 pixels for length and ±15° for angle. (For additional information on the display see the caption to Figure 2.)

key and the model were not eliminated. That Ai now drew more accurately than Pendesa, a complete reversal from probe trials in Experiment 1, suggests that the specific training Ai had received in Experiment 2 was important in bringing about control by the model. The complete-session data for Ai in Figure 15 indicate that the chimpanzee can be taught to draw a trace that is parallel to the model on most occasions.

## General discussion

Because our chimpanzee subjects do not have the requisite language to enable the teacher to use verbal instruction with success, we used "contingency-shaped" instruction. Thus, without any kind of "demonstration," "imitation," "assistance," "molding," or verbal instruction, the subjects eventually reached a moderate degree of success in drawing a line parallel to a model. Drawing on baseline trials for both subjects in Experiment 1 and for Pendesa in Experiment 3 showed that the subjects could be highly accurate when they connected two dots (see also Iversen & Matsuzawa, 1996). When the model was presented with only the startdot in Experiment 1, drawing was at first essentially random for Ai but Pendesa could draw a trace parallel to the model even though the trace was always too short. Encouraged by Pendesa's drawing on probe trials, we taught Ai to draw when the stopdot was gradually removed from the screen in Experiment 2. This fading or stimulus-control shaping procedure (e.g., McIlvane & Dube, 1992) was effective in generating model-guided drawing on many trials for Ai.

By the end of Experiment 3, both subjects demonstrated clear evidence that they have the ability to draw in the correct angle and the correct length under guidance by the model. The results suggest that the subjects do not lack necessary perceptual and motor components to draw accurately from a model. However, the performances were not stable, indicating that the stimuli we used did not guide performance optimally. A detailed behavior-pattern analysis (e.g., Iversen, 1991) of individual traces indicated that the instability of the performance was not random but instead reflected control by the prevailing stimuli and the immediate pretraining. Both subjects drew toward the trial-termination key on some trials or toward the model on other trials, revealing the competing sources of control over drawing. That is, the model itself and the trial-termination key began to serve the same function as the stopdot had served in previous sessions, even though drawing of such traces was never reinforced. For example, when Ai in Experiment 2 began to draw parallel to the model on some trials she also began to draw from the startdot toward the end of the model or toward the trial-termination key. Particularly compelling evidence that stimulus location was a critical determinant of drawing surfaced in Experiment 2 when we reversed the locations of the model and the startdot. Ai continued to draw where the startdot had been located before. Reversal of stimulus displays in other experimental situations (e.g., Iversen, Sidman, & Carrigan, 1986) similarly suggests that the locations of the training stimuli may become part of the controlling aspects of the stimuli.

The response patterns of drawing toward the trial-termination key, toward the model, or over the model as seen in the present experiments were clearly incompatible with appropriate control by the model. Sidman and Stoddard (1967) similarly presented evidence that errors, which emerged when retarded children were taught a form discrimination with a nonverbal teaching program, could be related to incompatible response patterns. Seen in a broader perspective, competing response patterns often contribute to deviations between expected and obtained measures of a single response of interest (Henton & Iversen, 1978). Thus, progress in both Ai's and Pendesa's performance was seen when we eliminated stimuli that controlled competing or "incorrect" drawing.

Our research was exploratory and we cannot yet pinpoint the conditions that are necessary to establish reliable single-line copying. The multiple-stroke contingency added in Experiment 3 improved drawing considerably and may be of general use in the teaching of drawing. In subsequent work on tracing of complex stimuli with the same subjects, we have found great utility in a similar multiple-stroke contingency. Possible improvements of our technique may be to locate the trial-termination key outside the drawing surface and to use more varied stimulus exemplars than we did here. For example, the startdot could be presented on either side of the model, and the model could appear in different lengths as well.

We suspect that an important element lacking in the present method is the explicit teaching of a relation between different spatial locations that have one dimension in common. Thus, for the subjects, the end of the model did not "correspond" spatially to the location of the stopdot. When Ai often drew traces that were much too long (especially for the 0° model) and when Pendesa consistently drew traces that were too short, their performances suggested that they had developed a fixed motor routine regarding trace length; the model controlled only the trace angle not the trace length.

Some studies of drawing in children have reported that oblique lines may be more difficult to draw than horizontal or vertical lines (e.g., Goldstein & Wicklund, 1973). In our study we found no evidence that oblique models produced poorer drawing than did vertical or horizontal models. However, the teaching methods we used to build drawing by progressing from pressing to sweeping (Iversen & Matsuzawa, 1996) and the contingency-shaping method in the present experiments are quite different from the approaches customarily used in studies of children's drawing. Hence, a direct comparison of drawing abilities across species and very different tasks may be premature.

Explicit teaching paradigms (verbal or nonverbal) for drawing and copying seem conspicuously lacking in the vast literature on children's drawing (e.g., Cox, 1992; Goodnow, 1977; Harris, 1963). In one study, Rand (1973) improved copying accuracy in 3–5-year-old normal children using a method of "demonstration and assistance." Developmentally delayed children, who may not respond appropriately to verbal instruction, are reported to improve drawing after having their hand guided by a teacher (e.g., Oppenheim & Rimland, 1974). Although still incomplete, the teaching methods developed in the present experiments for establishing model-guided, independent drawing in the chimpanzee may offer a way to establish basic drawing and copying skills in human subjects who lack such skills, without the use of verbal instruction, demonstrations, or other types of assistance. Thus, some human subjects with developmental disabilities similarly may not be able to acquire drawing skills through instructional methods that rely on language comprehension (e.g., Johnson & Myklebust, 1967). The precise recording and immediate visual feedback offered by the touch-sensitive monitor combined with the automated, on-line analysis of performance may form an ideal setting for establishing accurate drawing behavior in both human and nonhuman primates.

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## Appendix

### *Exact stimulus descriptions*

All stimulus dimensions are given in pixels. For the monitor used, 100 pixels equalled 5.83 cm. The QuickBASIC program used allowed a 640 ($x$-axis) × 400 pixel ($y$-axis) surface with (0, 0) at the upper left-hand corner. A white line 1 pixel wide marked the border of the drawing area. The trial-termination key was a white rectangle (90 × 80 pixels) located in the lower right-hand corner of the monitor. Finger movement over the monitor surface produced a series of contact points expressed as ($x$, $y$) pairs. Visual feedback of drawing (electronic ink) consisted of a blue disk (painted circle) presented at the exact spot the finger touched; the blue disk was 32 pixels in diameter (fingertip size). As the subject moved the finger over the monitor surface, a series of overlapping disks was produced that remained on the monitor until the trial ended. The series of disks thus formed the trace that represented the drawing behavior, hence the term "electronic finger painting." The guide dots on the monitor were two filled white dots (diameter 10 pixels). The model appeared as a homogeneous blue bar 32 pixels wide with rounded ends. The bar was composed of two blue disks (diameter 32 pixels) as endpoints with the area between the disks filled with blue. The distance between the endpoints was 200 pixels. The exact length of the bar from end to end was the distance between the centers of the end disks plus two times the radius of the end disks. The centers of the two guide dots were aligned with the centers of the end disks of the bar. Because diagonal model orientations were 45° and 135°, the lateral difference between the two guide dots or the centers of the end disks of the model was always 141 pixels (i.e., $200/\sqrt{2}$). Thus, if the startdot is located at (350, 100) for the 45° model, for example, then the stopdot is located at (209, 241).

The locations of the models are given as coordinates (*x, y*) of the center of the model endpoints; the locations of the guide dots are given as coordinates (*x, y*) of the center of the dot, with the startdot presented first. In general, the model was located 120 pixels to the left of the guide dots for the 45°, 90°, and 135° models. For the 0° model, the guide dots were either 120 pixels above or under the model, depending on the procedure.

Experiment 1: 0° model from (400, 100) to (200, 100) with guide dots (400, 220) and (200, 220); 45° model from (300, 100) to (159, 241) with guide dots (420, 100) and (279, 241); 90° model from (200, 100) to (200, 300) with guide dots (320, 100) and (320, 300); 135° model from (80, 100) to (221, 241) with guide dots (200, 100) and (341, 241).

Experiment 2: stimuli were rearranged so that the 0° model had the bar and the guide dots reverse location by placing the dots above the bar; in addition, the 0° and the 45° models shared one startdot at (350, 100) and the 90° and the 135° model shared a second startdot at (200, 100): 0° model from (350, 220) to (150, 220) with guide dots (350, 100) and (150, 100); 45° model from (230, 100) to (89, 241) with guide dots (350, 100) and (209, 241); 90° model from (80, 100) to (80, 300) with guide dots (200, 100) and (200, 300); 135° model from (80, 100) to (221, 241) with guide dots (200, 100) and (341, 241).

Experiment 3: the 0° model was not presented, and the stimuli were rearranged so that all models shared the same startdot location at (300, 100); 45° model from (170, 100) to (29, 241); 90° model from (170, 100) to (170, 300); 135° model from (170, 100) to (311, 241).

### *Reinforcement criteria*

The series of touch points generated by finger movement was analyzed automatically (on-line) in each trial to determine whether or not to reinforce that trial. In addition, the touch points were stored for each trial for later analysis. An additional bit of stored information was when the subject lifted the finger from the monitor; this information was used in Experiment 3 to analyze multiple strokes.

By pressing the trial-termination key after having drawn on the monitor, the subject caused the program to analyze the drawn trace. The press on the trial-termination key did not leave any visual ink on the monitor and was not analyzed as part of the drawn trace. If the subject pressed the trial-termination key before having drawn anything, the trial either terminated or continued, depending on the procedure. Because the ideal response is to draw a straight line that connects the two guide dots, the data are analyzed from that perspective. The program forms an invisible line between the first ($a$) and last touch point ($b$). The distance (in pixels) between $a$ and $b$ is defined as the length of the drawn trace. The angle to horizontal of the line formed between $a$ and $b$ is defined as the orientation (angle) of the drawn trace. The variability of the drawn trace is analyzed as the average scatter of the touch points around the invisible line formed between $a$ and $b$. The absolute perpendicular distance from each touchpoint to this line is summed for all touchpoints. Because the first and last touchpoints by definition lie on this line, the sum of the deviations around the line is divided by the number of touchpoints less 2. The program assessed in less than 100 ms whether the drawn trace satisfied the reinforcement criteria.

According to these criteria, a perfectly drawn trace will have a length of 200 pixels and an orientation (angle) identical to the orientation of the two guide dots (or the model) and a variability of zero pixels (i.e., all touch points lie on a straight line).