STIMULUS EQUALIZATION:

A computer-based stimulus manipulation procedure for facilitating visual discriminations

by

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ABSTRACT

This study examined the practicality and instructional effectiveness of a computer-based procedure to facilitate visual discriminations. A video monitor controlled by an APPLE II+ microcomputer displayed groups of four stimuli differing along several dimensions. Characteristics of stimuli were scrambled forming new combinations across the 16 trials each session. Five preschool children participated by using a trackball to "find Freddy." During each phase of the study an element from a different dimension was designated as S+. Responses, stimulus characteristics, and latencies were recorded and immediately analyzed by the computer. When trial-and-error was not sufficient differences along irrelevant stimulus dimensions were equalized (or eliminated) and later reinstated once correct responding was occurring. Stimulus equalization was found to be successful in 71% of the cases where trial-and-error training was ineffective. The results indicate that stimulus equalization is an efficient, effective teaching procedure and the response analysis yielded valuable information concerning the children's error patterns. The potential benefits of such an analysis and stimulus manipulation possibilities are discussed.

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The automating of instruction through teaching machines is not new. In the 1920's, Sydney Pressey developed a machine that "taught" individuals by presenting academic items one at a time and requiring the student to make an overt response to each item (Pressey, 1926). In the 1950's, learning by machine achieved new credibility through the advocacy and creations of B. F. Skinner and other educator-scientists (Lumsdaine & Glaser, 1960). Although many predicted that these teaching machines would revolutionize the educational process, no such revolution occurred (Vargas, 1984).

Perhaps the use of machines to instruct individuals did not flourish because of their expense and functional limitations. Often the learning program had to be altered to accomodate the machines on which they were presented rather than altering the machine to accomadate the learning program. It was clear that advances in electronic technology as well as advances in educational technology were needed.

Systematic research in electronic technology has resulted in the most versatile and powerful teaching machine to date--the computer. Computers are no longer expensive, complicated machines with limited capability. They have been used to teach a variety of skills successfully (Atkinson, 1974; Blank, 1982; Cohen & Schwartz, 1983; Collins, Adams, & Pew, 1978; Holland & Doran, 1972; Lally, 1980, 1981; Oberting, 1974; Tait, Hartley, & Anderson, 1973; Well & Bell, 1980) and to instruct numerous individuals with diverse backgrounds and skills (Boothroyd, Archambault, & Adams, 1975; Colby, 1973; Culbertson, 1974; Evans & Simpkins, 1972; Fletcher & Atkinson, 1972; Foulds, 1982; Hoffmeyer, 1980; Saracho, 1982; Schiffman, Tobin, & Buch, 1982; Stutzman, 1981; Thomas, 1981). Computers have even been used with children in rural areas more than 900 miles from the computer (Tawney, Aeschlemann, & Denton, 1979). It is clear that the needed electronic technology is now available.

Much of the machine's success is undoubtedly due to its vast capabilities. The computer is capable of presenting and manipulating stimuli, keeping track of student responses (including various aspects of those responses such as their frequency, latency, accuracy, etc.), and performing intricate analyses of those responses (LeBlanc, Hoko, Etzel, & Aangeenbrug, 1984). Such analyses are important in that they help the teacher or researcher to discover the environmental variables that are interfering with learning rather than merely stating that the child is not learning or that the child is responding at chance level (Sidman, 1960). A thorough analysis of the errors that occur during a learning task could be accomplished easily with the aid of a microcomputer. Such an analysis would help identify inappropriate stimulus control that may be occurring. If such inappropriate stimulus control can be identified during the learning process, the computer could alter the program in a way that would facilitate learning. The superordinate investigation of the nature, types, and parameters of such alterations is made possible by the computer.

Educational technology has also progressed. Programmed instruction (Holland & Skinner, 1961) and personalized systems of instruction (Keller, 1968) are evidence of the importance of sequencing academic material and providing appropriate consequent events. Research has also provided valuable information concerning the role of antecedent events during learning. Etzel and LeBlanc (1979) outlined several stimulus manipulation procedures (such as stimulus fading, shaping, and superimposition) that have proven successful for facilitating learning in classrooms as well as in the laboratory for individuals who are commonly considered "slow learners", such as autistic and retarded children. A major disadvantage of stimulus manipulation procedures, however, has been that both much skill and time were required to design, produce, and implement the specific program needed to overcome a specific learning problem. The stimulus manipulations were often difficult to create, and the prompt error analyses needed to provide program flexibility were nearly impossible for the classroom teacher, tutor, or other educator to conduct. Yet, a computer, properly programmed, can solve these problems and thus permit such procedures to be commonly used.

Combining advanced computer technology with the most current educational technology is a strategy rarely seen in learning environments even though such a strategy should enhance the completeness and quality of education today. Superimposition, stimulus fading, and stimulus shaping are only a few of the stimulus manipulation procedures that may be expertly performed by a computer. Other manipulations of stimuli which are especially easy for the computer to implement, such as changing the values or elements of stimulus dimensions to "simplify" visual discriminations.

Children often have difficulty learning to discriminate between multidimensional stimuli (Lockhead, 1966). Discriminations often are easier to acquire when differences along irrelevant stimulus dimensions do not exist (Granzin & Carnine, 1977; House & Zeaman, 1960; Pomerantz & Garner, 1973). For example, teaching a child to discriminate blocks of different shapes would be easier if the blocks differed only in shape (i.e. all of the blocks were the same color, size, weight, etc.). Eliminating irrelevant dimensional differences of stimuli may facilitate learning if training with multidimensional stimuli is ineffective. Such a procedure could be performed easily by a computer since response analyses are performed quickly and easily, and stimuli are created by specifying a value or element for each dimension. For example, one computer-presented stimulus might be a large, bright, red, triangle while another may be a small, dim, blue square. Quickly changing the value or element of a stimulus, such as making the triangle small and green, is easily done by the computer.

This study examined the practicality and instructional effectiveness of a computer-based procedure during which irrelevant dimension differences of complex stimuli are equalized (or eliminated) to facilitate correct responding and then reinstated once appropriate responding is stablized. Such a technique could be initiated by the computer on the basis of an analysis of subject responding.

Method

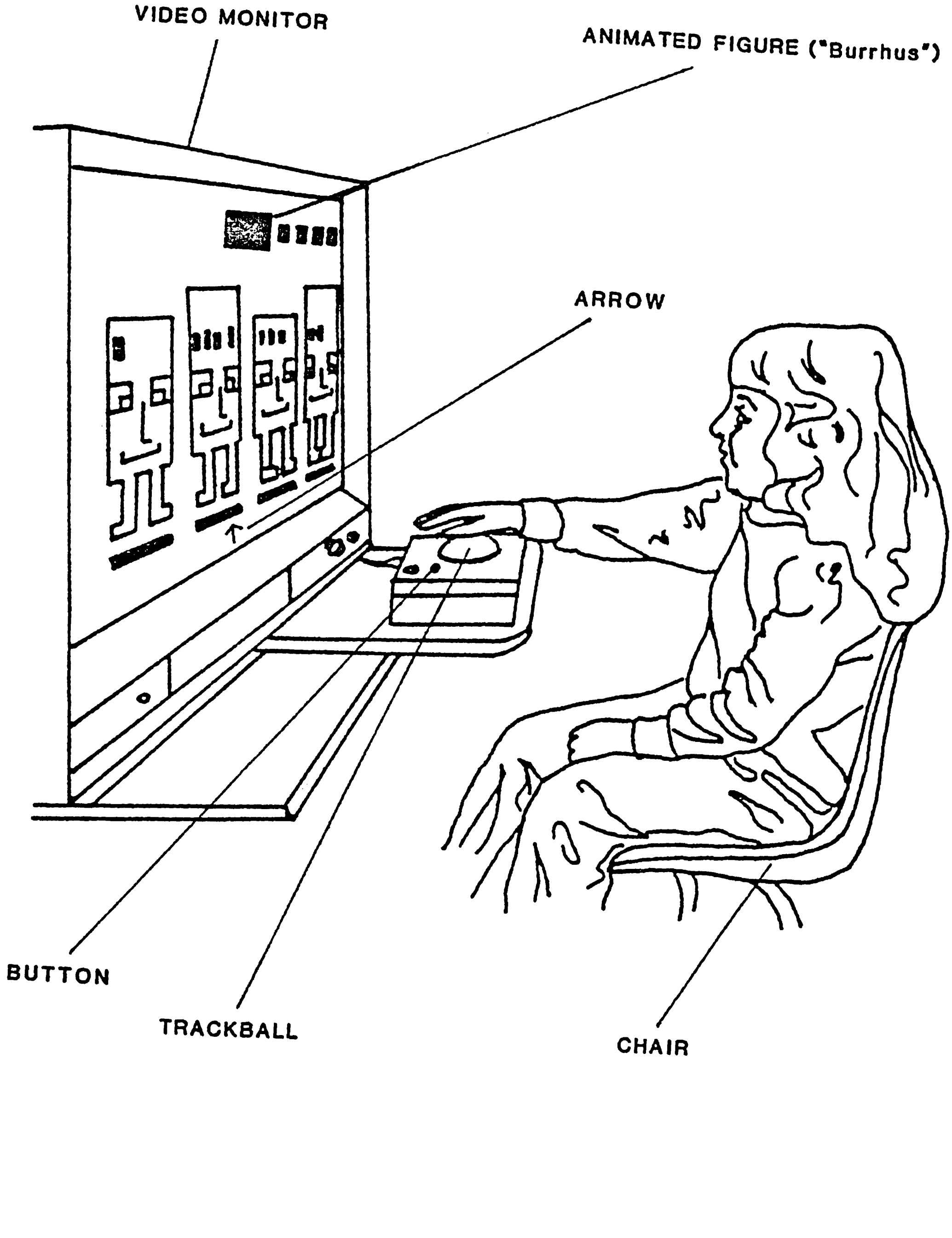
Subjects.

Five children participated in the present study including three boys (subject 16, subject 17, subject 22) aged three years, 10 months, four years, 11 months and three years, five months, and two girls (subject 23, subject 24) ages three years, 11 months and four years, 10 months. All of the children were attending preschool classes in the Edna A. Hill Child Development Laboratory at the University of Kansas and were selected from a group of nine children because they failed to learn two of four discrimination tasks during trial-and-error training.

Setting and Apparatus.

An APPLE II+ microcomputer equipped with a 16K language card, two APPLE II disk drives, and a green phosphorus monochrome video monitor was located in an observation room (4m x 3m) and was used to control a 19 cm color video monitor located in an adjacent experimental room (5m x 4m). Also in the experimental room were two child-sized wooden chairs and an APPLE compatible trackball attached to a table in front of the monitor through which the child could respond to the stimulus presentations (see Figure 1). The two

Figure 1. Representation of the experimental setting.


VIDEO MONITOR
ANIMATED FIGURE ("Burrhus")
ARROW
BUTTON
TRACKBALL
CHAIR

rooms were separated by a one-way mirror. During all sessions the experimenter remained with the child in the experimental room and during some sessions an independent observer located in the observation room recorded reliability of the dependent and independent variables.

The computer programs were written by the experimenter using APPLE's DOS 3.3 and Applesoft (APPLE's version of floating point Basic) for data collection and analysis. APPLE's SuperPILOT authoring system was used to construct the audio/graphics routines.

General Procedure.

During each of the experimental phases the child was brought into the experimental room, told to sit in the red chair in front of the video monitor, and given some brief instructions. The instructions included an explanation of the stimuli to be presented and a description of how the subject was to respond to the several stimulus displays that would follow.

Each session involved several presentations of four line drawings on the color video monitor. The child was required to respond to one of the four stimuli (line drawings) by rolling the trackball either left or right to position an arrow of light displayed on the monitor screen under the stimulus of choice (see Figure 1) and then pressing a red button located on the base of the trackball. Responses to the "correct" stimulus resulted in three short beeps on the audio speaker and an animated figure "eating cookies" in the top portion of the video screen. This sound and animation routine was used as a potential reinforcement system throughout the study. Responses to an incorrect stimulus resulted in a 1-sec tone and 5-sec of a motionless video screen. A 5-sec intertrial interval during which the screen was blank and responses on the trackball had no consequences occurred between all stimulus presentations.

Twenty audio/graphic routines were implemented as potential back-up reinforcers subsequent to sessions during which the frequency of correct responses reached a prespecified level. Each audio/graphic routine consisted of a short tune followed by a computer drawing and another short tune (see Appendix A). The routines were sequentially selected for use by the experimenter prior to the session. The number of correct responses required for the audio/graphics routine to occur was set at one correct response for the first session of an experimental condition, was increased by two each time the criterion level was reached during a session, and was decreased by two each time the criterion level was not reached during a session. The required criterion level remained the same if the adjustment would have permitted less than one correct response or more than the possible sixteen correct responses to produce the audio/graphics routine. The adjusting criterion rarely permitted omission of the audio/graphics routine for more than two consecutive sessions for any given child (see Appendix B).

Specific Procedures.

Format training. The child was brought into the room and told to sit in the chair facing the video monitor. The trackball was located directly in front of the child (see Figure 1). The experimenter explained the reinforcement system to the child:

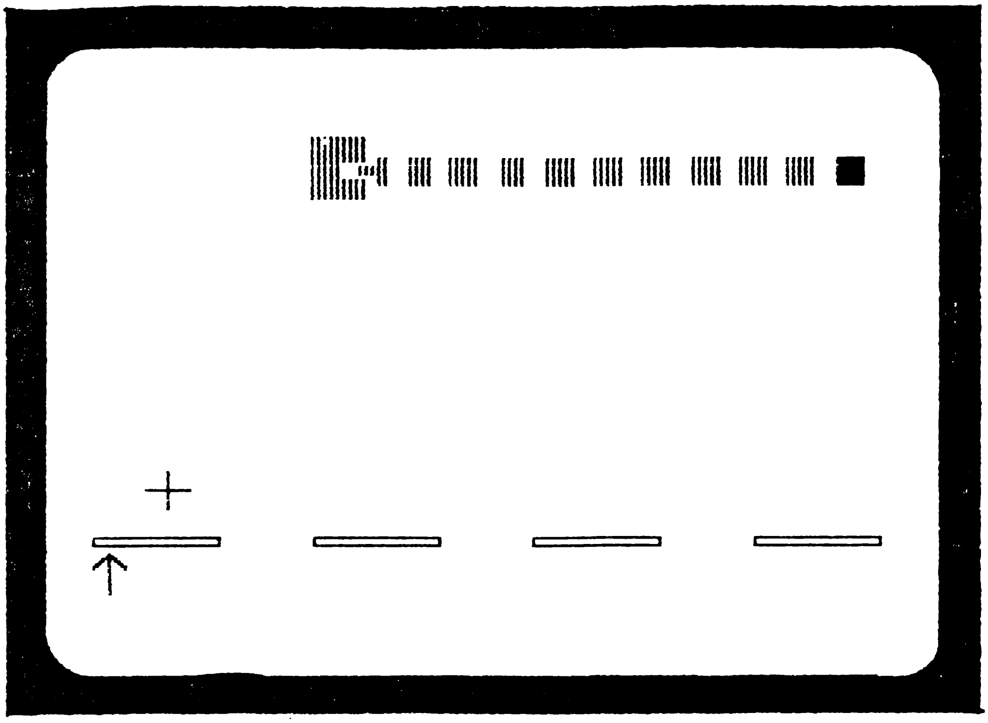
> Today we're going to play a game on the computer. This is Burrhus [the experimenter points to Burrhus]. Burrhus likes to eat cookies [the experimenter points to cookies]. Every time you roll the trackball to move the arrow by my finger and press the red button Burrhus will eat some cookies [the experimenter points to one of the four screen positions with one hand and models the correct response with the other; three short

> beeps occur and the animated figure "eats some cookies"] If Burrhus eats enough cookies he'll draw you a picture and sing you a song. Now it is your turn. Roll the ball to move the arrow by my finger then press the red button [Across several trials the experimenter gradually requires arrow to come closer to his finger before activating the token system and providing verbal praise].

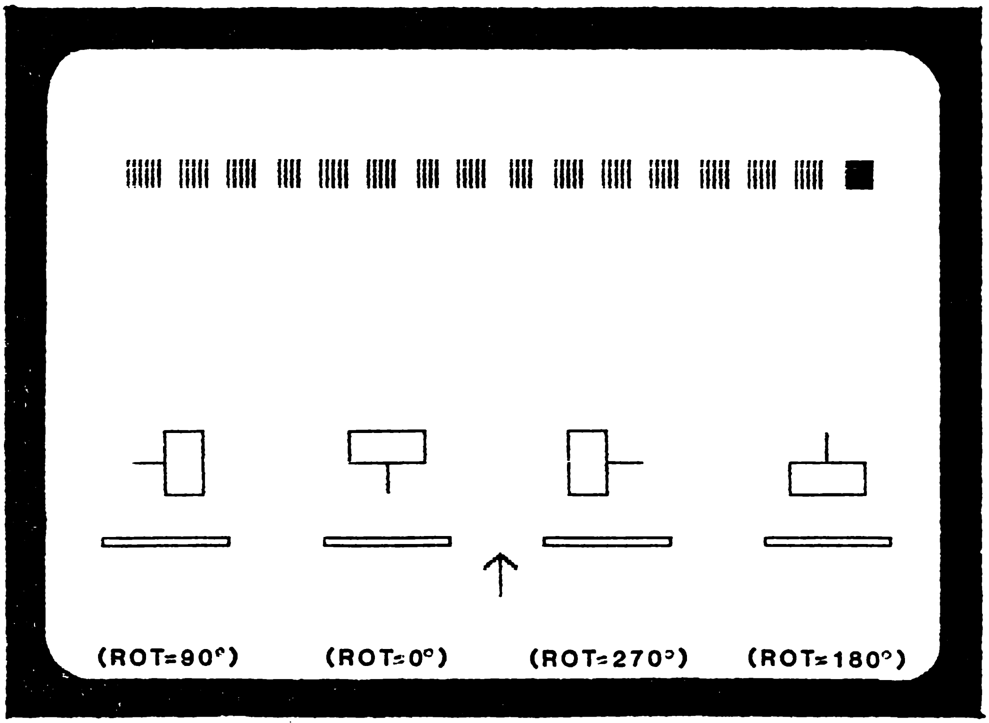
During this phase of the study only the arrow appeared on the video screen and every session was concluded with a brief audio/graphics routine. Once the child was judged by the experimenter to be responding accurately to the experimenter's finger placement (usually in two to four sessions) a computer-presented stimulus was introduced in the form of a cross (+) in lieu of the finger placement (see Figure 2). The experimenter explained:

> Today we're going to do something a little different. This is my cross [the experimenter points to cross] and this is your arrow [the experimenter points to arrrow]. Your job is to move the arrow under my cross then press the red button. If your arrow is under my cross when you press the red button Burrhus will eat some

Figure 2. Representation of the format training stimuli (top frame) and pretraining stimuli (bottom frame). In the bottom frame the right-most stimulus is rotated 180 degrees; children were trained to respond to this stimulus during pretraining.



FORMAT TRAINING STIMULI



PRETRAINING STIMULI

cookies.

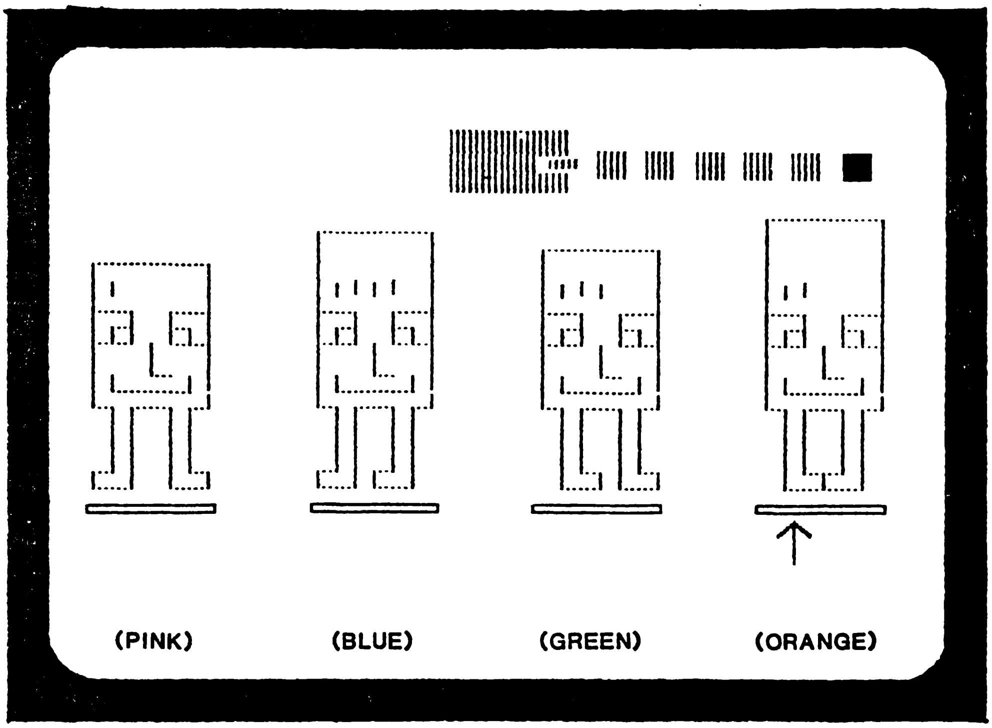
Pretraining was initiated after the child was accurately positioning the arrow beneath the cross for several consecutive trials (usually in one to two sessions).

Pretraining. Stimulus displays now consisted of a simple line drawing displayed in four orientations (0, 90, 180, and 270 degs) along the same horizontal plane of the video screen (see Figure 2). When the child was quiet and looking at the video monitor the experimenter said, "These are Burrhus's toys. One of them is called an ogg. To make Buhurrus eat some cookies roll the trackball and move the arrow under the ogg then press the red button." Responses to the stimulus that was rotated 180 degs were immediately followed by three short beeps and an animated figure eating cookies. Responses to all other orientations of the stimulus were followed by a 1-sec tone and a 5-sec motionless video screen. Button presses occurring while the arrow was not directly beneath one of the four drawings were inconsequential.

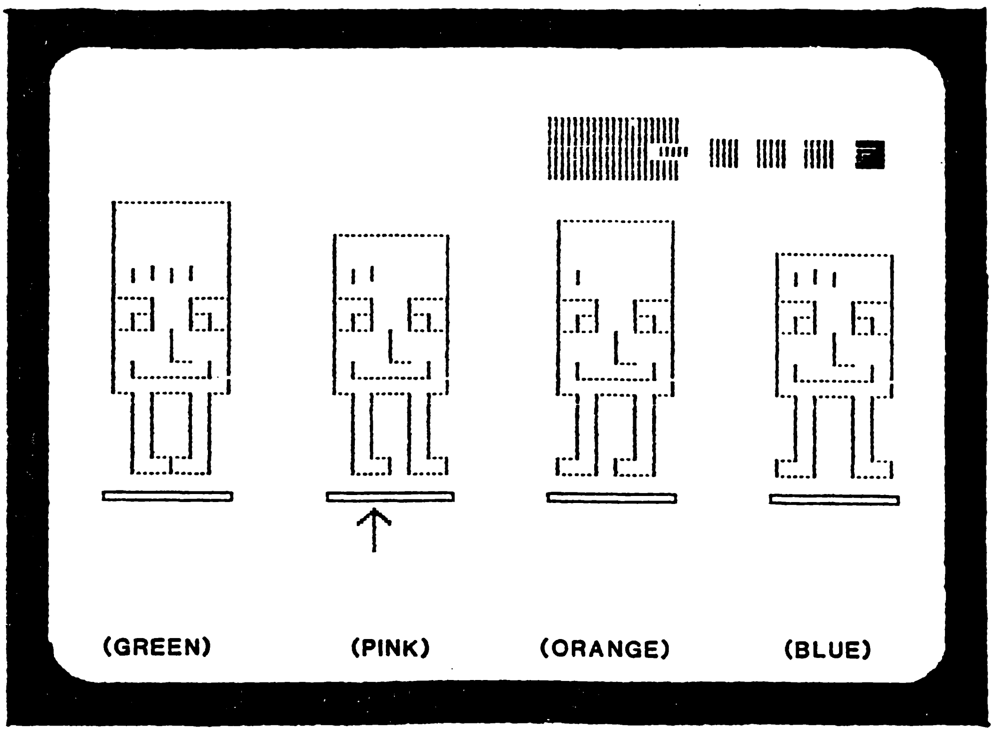
Each session during pretraining consisted of 16 presentations of stimulus displays. The orientation of the stimuli were randomized such that a specific orientation never occurred in the same screen position twice in succession and each orientation occurred in each screen position once every four trials. An 5-sec intertrial interval during which the screen was blank occurred between all stimulus presentations. Responses with the trackball were inconsequential during this intertrial interval. Every session was concluded with a brief audio/graphics routine. When the child responded to the stimulus rotated 180 degrees, during the last eight trials of two consecutive sessions, training was initiated.

Training. The stimulus displays consisted of four complex line drawings (see Figure 3). The four stimuli differed along four dimensions: number of hairs, size, color, and position of feet creating a total of 16 different dimensional elements (one to four hairs, four sizes, four colors, and four feet positions). Each of the line drawings was 4 cm in width and ranged in height from 11 cm to 14 cm (in 1 cm steps). The computer was programmed to create each of the four stimuli by incorporating one element from each of the four dimensions. The stimuli therefore had four different numbers of hairs, were of four different sizes, were of four different colors, and had four different feet positions. Systematic randomization of

Figure 3. Representations of complex training stimuli. The bottom frame is included to show how stimulus elements are randomized across trials.



COMPLEX STIMULI (1st)



COMPLEX STIMULI (2nd)

the 16 stimulus elements assured that (1) each element was presented in each screen position every four trials, (2) no element ever occurred in the same screen position more than twice in succession, (3) no two elements ever occurred together more than twice in succession and, (4) each element had three other elements (one from every other dimension) with which it never occurred (e.g. two hairs never occurred in the same stimulus as small, green, or left-right feet). These conditions are displayed in Table 1.

Sessions consisted of 16 presentations of the stimulus display and every three sessions each of the 24 possible stimulus displays was presented twice on the video screen. Prior to the first session of training, the experimenter explained to the child, "These are Burrhus's friends. One of them is named Freddy. To make Burrhus eat some cookies roll the trackball and move the arrow under the friend named Freddy then press the red button." Responses to the stimulus containing the element preselected by the experimenter (see Conditions section) were followed by the sound and animation routine. Responses to all other stimuli were followed by a single 1-sec tone and 5-sec of a motionless video screen. A 5-sec intertrial interval during which the screen was blank and responses to the trackball were ineffective occurred

ORTHOGONALITY OF THE STIMULUS
ELEMENT RANDOMIZATION

HAIRS	SIZE	COLOR	FEET
two*	small*	green*	L/R*
three	medium	pink	L/L
four	large	orange	R/R
one	x-large	blue	R/L

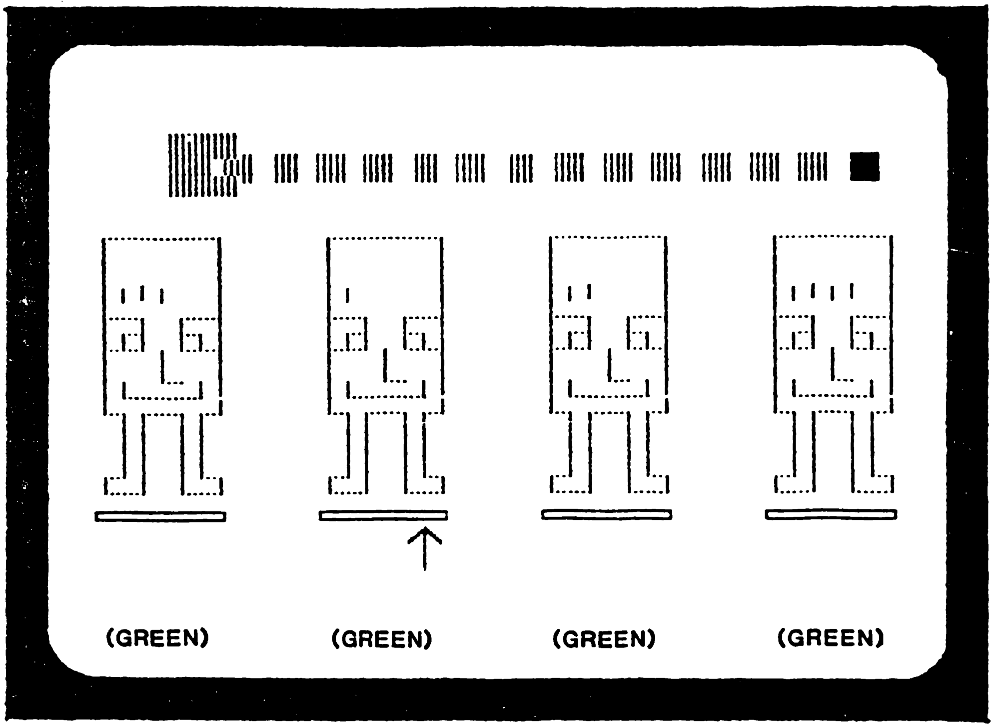
*stimulus element which was reinforced during some experimental conditions between stimulus presentations. Training also differed from pretraining in that the audio/graphics routine was presented only at the end of sessions during which the frequency of "correct" responding reached a certain criterion level (specified in the General Procedure section).

Experimental Manipulations.

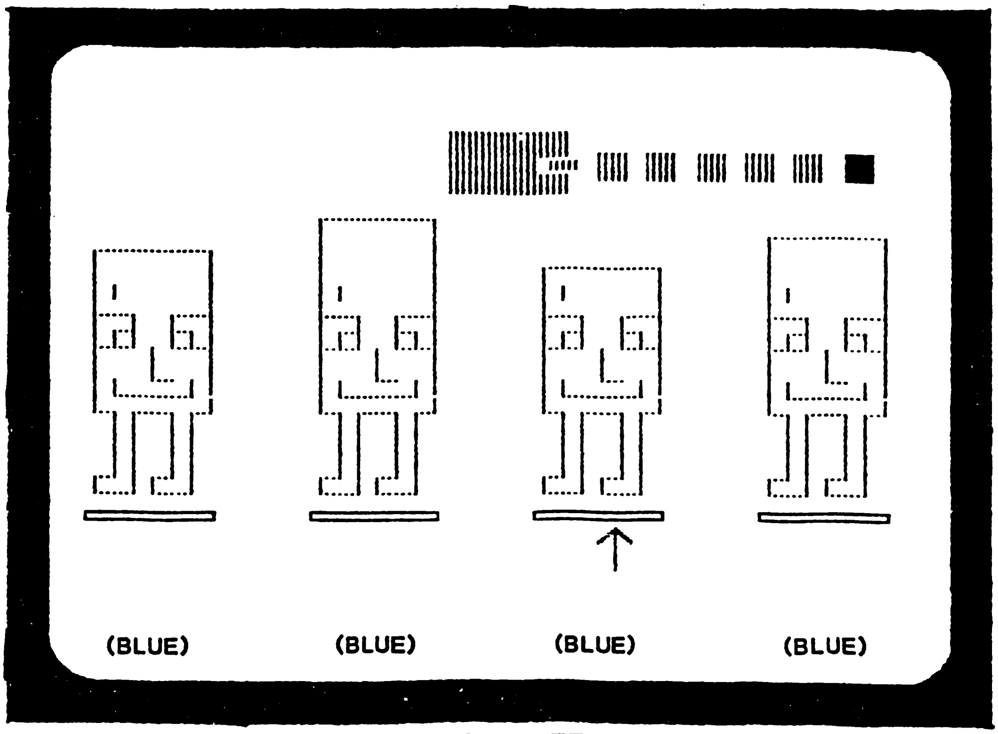
Stimulus Equalization. During this phase the stimuli differed only along the dimension containing the stimulus element correlated with the sound and animation routine (e.g. if a response to the stimulus containing two hairs was to be reinforced the stimuli would all be the same size, the same color, and have the same feet position, but would each have a different number of hairs--see Figures 4 and 5). If the child responded correctly during the last eight trials of two consecutive sessions as well as during trials four through eight of a third session the experimental condition was immediately changed to regular training (i.e. all of the dimensional differences present in the original stimuli were immediately reinstated) on the ninth trial of that third session.

Experimenter verbalizations and tacting. Verbalizations were recorded when the experimenter

Figure 4. Representation of stimuli during equalization training for a hairs discrimination (top frame), and for a size discrimination (bottom frame).

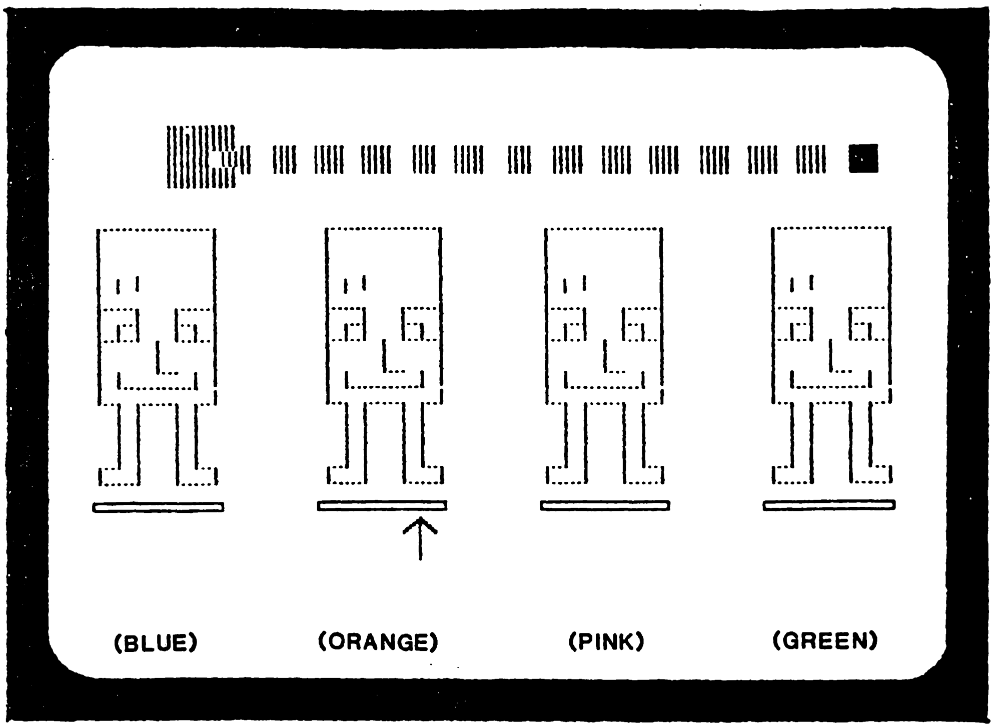


ALL DIMENSIONS EQUALIZED EXCEPT HAIRS

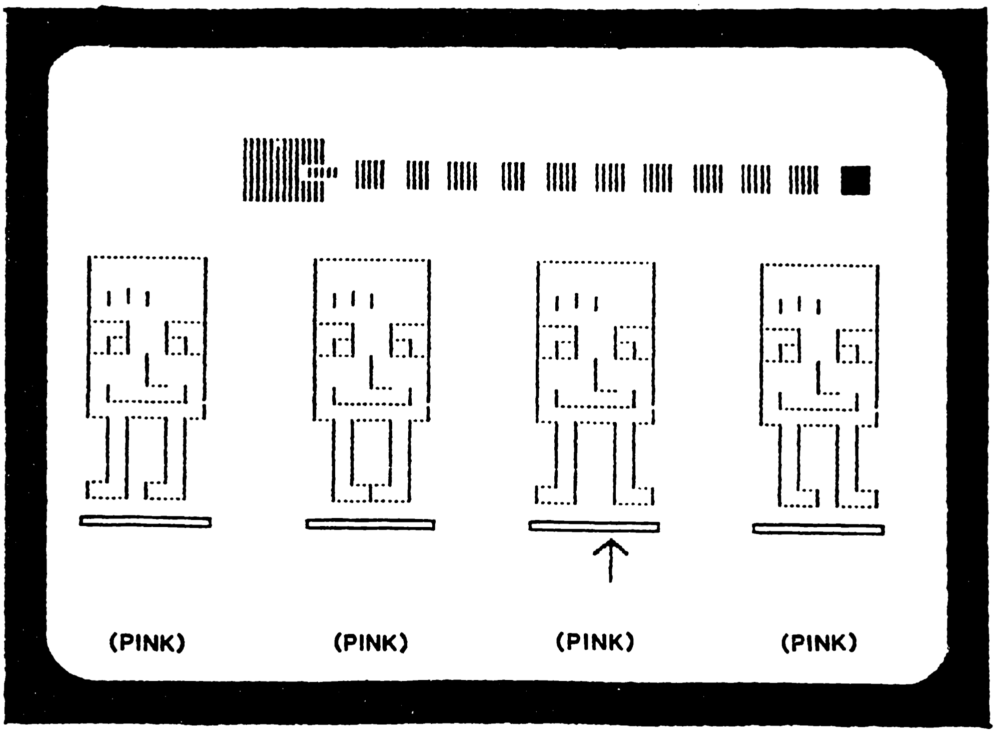


ALL DIMENSIONS EQUALIZED EXCEPT SIZE

Figure 5. Representation of stimuli during equalization training for a color discrimination (top frame), and for a feet orientation discrimination (bottom frame).



ALL DIMENSIONS EQUALIZED EXCEPT COLOR



ALL DIMENSIONS EQUALIZED EXCEPT FEET

verbally prompted the child to respond to the stimulus displays. A verbalization was defined as any statement by the experimenter directed to the child during an experimental session. Examples of experimenter verbalizations include such statements as: "Remember to press the red button", "Roll the ball to move the arrow under Freddy", "That friend is not Freddy", and "Good! You found Freddy and see Burrhus is eating some cookies." Verbalizations were recorded by the experimenter along with the response and computer consequences data (see Recording section).

A tact was defined as a verbal statement by the experimenter that occurred before the first child response of a session and that specified the stimulus dimension relevant to correct responding. If the child was being taught to select the stimulus with two hairs the experimenter might tact the hairs dimension by saying, "Look at Burrhus' friends. Each of them has a different number of hairs [the experimenter points to each of the four stimuli]. One of the friends is Freddy. Your job is to find Freddy." or if the relevant dimension was color the experimenter might say, "Look at Burrhus' friends. Each of them is a different color [the experimenter points to each of the four stimuli]. One of the friends is Freddy. Find Freddy." To facilitate learning of the visual discriminations, tacts were implemented when stimulus equalization did not result in an increase in correct responding from some baseline level to 90-100% correct responding within a few sessions.

Conditions.

Experimental conditions differed in terms of the element that was correlated with the sound and animation routine. Conditions changed when the child had responded to the correct stimulus on each of the last eight trials of two consecutive sessions and during trials four through eight of a third session. The condition immediately changed on trial nine of that third session. For four subjects (subject 16, subject 22, subject 23, subject 24) the sequence of elements correlated with the sound and animation routine was: two hairs, small, green, left-right feet (see Table 2). For one subject (subject 17) the sequence was: two hairs, left-right feet, green, small. Stimulus equalization was initiated after three to nine sessions of unsuccessful trial and error training of an element. Tacting of the relevant stimulus dimension occurred after several sessions of unsuccessful stimulus equalization training.

EXPERIMENTAL CONDITION SEQUENCE

Subject	Sequence of reinforced stimulus elements								Total no. of sessions
S-16	two hairs*	small*	green	L/R feet*	--	--	--	--	49
S-17	two hairs	L/R feet*	green	small*	two hairs*	--	--	--	36
S-22	two hairs*	small*	green*	L/R feet	two hairs	green	--	--	51
S-23	two hairs*	small*	green	L/R feet	two hairs	green	small	L/R feet*	56
S-24	two hairs*	small*	--	--	--	--	--	--	54

*stimulus equalization occurred subsequent to regular training

Recording.

During experimental sessions the microcomputer automatically recorded (and stored to floppy disk) the child's response, the positions of the 16 elements, and the response latency. During every training, session the experimenter recorded the child's response as well as any experimenter verbalizations that may have been necessary for the experimenter to provide during a particular trial (see Appendix D).

Appendix C depicts a data sheet which could be printed by the computer at some time following an experimental session. The lower half of the data sheet is a response analysis grid which provides information concerning characteristics of individual responses. Stimulus elements are listed on the left with trials indicated along the abscissa. Location of the X's in a column indicate characteristics of the stimulus responded to on a particular trial; horizontal strings of X's indicate consecutive responses to a particular stimulus element. This response analysis grid is an expansion and modification of an error analysis grid developed and used by Covill-Servo and Etzel (1976) and serves to quickly identify consistencies of stimuli responded to during an experimental session.

<u>Reliability.</u>

During 36% of the experimental sessions, observations were conducted by an independent observer located in the observation room. These observations occurred weekly and at least one observation occurred during each experimental condition. The reliability observer recorded the occurrence of the child's trackball response to a particular stimulus, whether or not the sound and animation routine occurred, and the occurrence of any experimenter verbalizations during each of the 16 trials per session (see Table 3).

The reliability measurement for the trackball response was calculated by comparing the trial-by-trial data of the microcomputer with that of the reliability observer using the following formula: # of agreements / total trials x 100. For all of the subjects, the total reliability of the trackball response ranged from 98.4% to 100% with a mean of 99.33%.

The reliability measurement for the presentation of the sound and animation routine and experimenter verbalizations was calculated by comparing the trial-by-trial data of the microcomputer with that of the reliability observer using the following formula: # of agreements / # of agreements and disagreements x 100. An agreement was defined as when both the microcomputer and the reliability observer recorded an

RELIABILITY

Subject	Trackball Responses*	Experimental Verbalizations**	Reinforcement Routine**
S-16	100.0%	94.6%	100.0%
S-17	99.2%	93.3%	98.3%
S-22	99.0%	85.0%	99.2%
S-23	100.0%	100.0%	100.0%
S-24	98.4%	90.5%	98.9%

*total reliability
**occurrence reliability

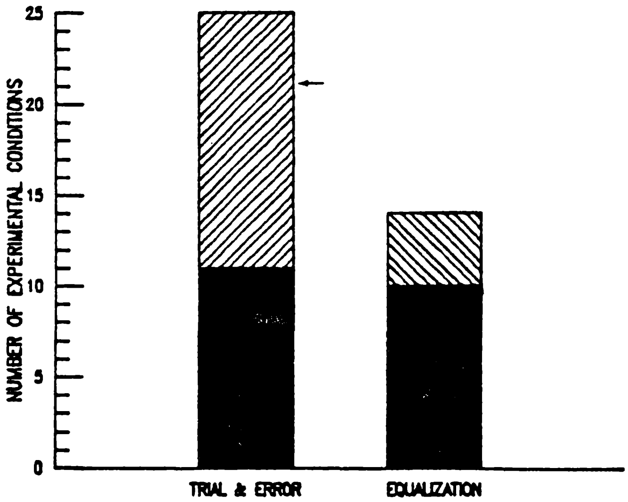
occurrence of the behavior. A disagreement was defined as when either the computer or the observer (but not both) recorded an occurrence of the behavior. For all of the subjects, the total reliability of the presentation of the sound and animation routine ranged from 98.3% to 100% with a mean of 99.3%. The reliabilty of experimenter-observer agreement on the occurrence of experimenter verbalizations ranged from 85% to 100% with a mean of 92.7%.

Results

Figure 6 indicates the effectiveness of both trial-and-error and equalization training. Training was considered effective or successful if, during its implementation, the frequency of correct responsed increased from some baseline level to between 90 and 100% correct responding and maintained at that level until the criterion for progression to the next experimental condtion was met. The blackened portion of the left bar indicates that trial-and-error training was effective in only 11 (44%) of the 25 experimental conditions in which it was attempted. The right bar shows that stimulus equalization training occurred in 14 experimental conditions (those in which

Figure 6. Number of experimental conditions involving successful trial-and-error or equalization training. The blackened area denotes successful training.

EFFECTS OF TRIAL & ERROR AND EQUALIZATION TRAINING★



★blackened area depicts successful training trial-and-error training was unsuccessful) and was successful (black area) in 10 (71%) of the 14 instances in which it was implemented. The arrow along the left bar shows that trial-and-error training and/or stimulus equalization resulted in successful training of 21 of the 25 visual discriminations.

The experimental conditions involved visual discriminations along several stimulus dimensions. Table 4 shows the relative effectiveness of the two training procedures across the dimensions of hairs, size, color, and feet. Eight of the 25 experimental conditions involved a visual discrimination of an element in the hairs dimension. Trial-and-error training alone was sufficient in three (38%) of the eight conditions. Stimulus equalization was implemented in the remaining five conditions and was successful in four (80%) of them.

The next vertical column shows that trial-and-error training was successful for only one (17%) of the six experimental conditions in which a size discrimination was involved. Stimulus equalization was again effective in four (80%) of the five conditions in which it was implemented.

Trial-and-error training alone was most successful for color discrimination tasks. Of the six experimental conditions in which color was the relevant

EFFECTS OF TRIAL & ERROR AND EQUALIZATION TRAINING ACROSS STIMULUS DIMENSIONS

	Stimulus Dimensions				
	HAIRS	SIZE	COLOR	FEET	ALL
No. of experimental conditions	8	6	6	5	25
No. of times trial & error successful	3	1	5	2	11
Percentage of times trial & error successful	38	17	83	40	44
No. of exp. conditions involving equalization	5	5	1	3	14
No. of times equalization successful	4	4	1	1	10
Percentage of times equalization successful	80	80	100	33	71

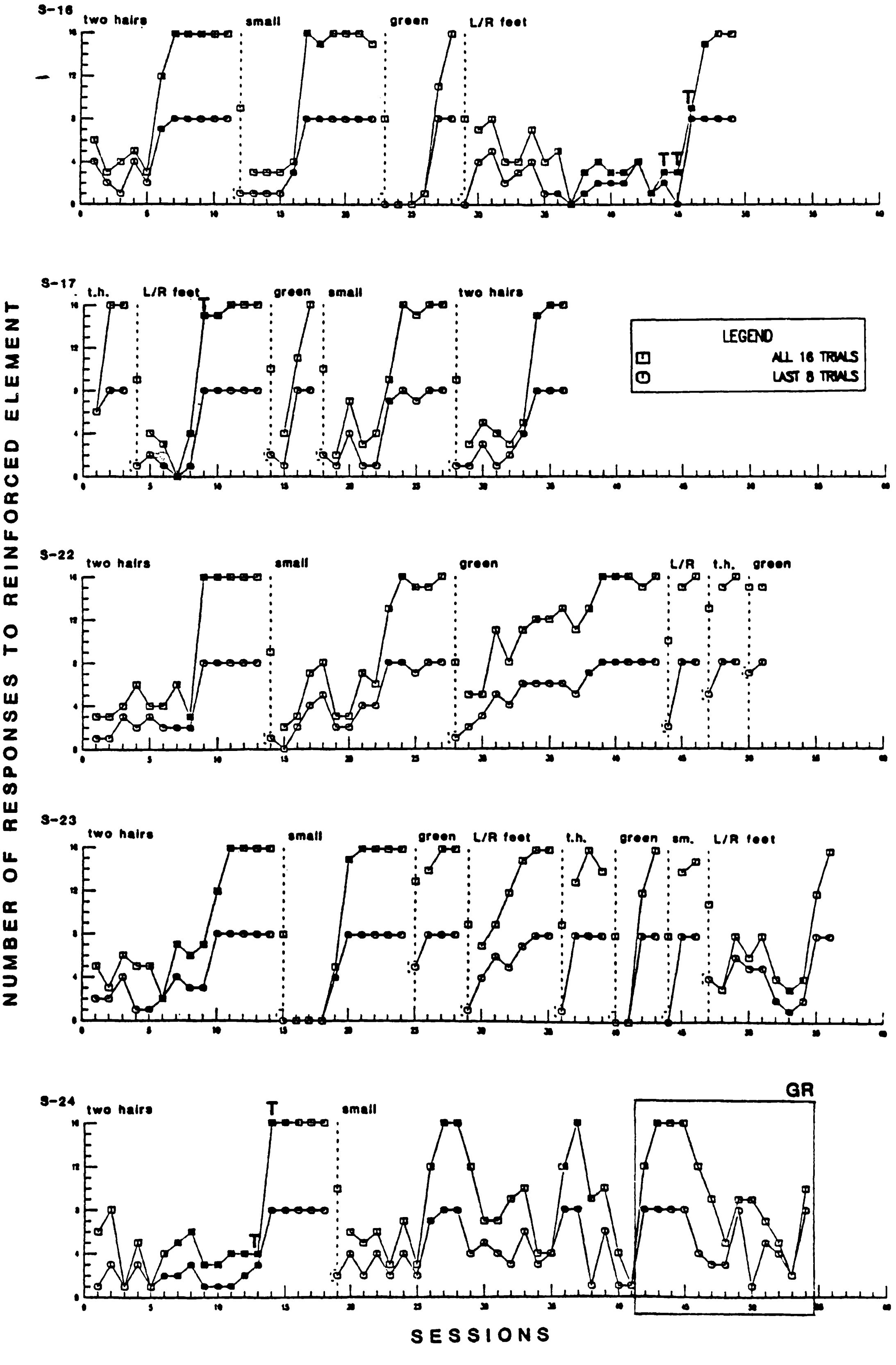
stimulus dimension, trial-and-error training was effective five times (83%). Stimulus equalization was found to be effective in the remaining condition (100%).

Only five of the 25 experimental conditions involved a discrimination of feet position. Trial-and-error was effective for two (40%) of the five conditions, while equalization was effective for only one (33%) of the other three condtions.

Figure 7 portrays the session-by-session performance of each of the five children. Experimental conditions are labelled along the top of each graph with the name of the stimulus element being reinforced and are separated by vertical dashed lines. Squares indicate the total number of reinforced responses per session, while circles indicate the number of reinforced responses during the last eight trials of a session. The filled-in (black) squares and circles indicate that stimulus equalization was occurring. A small uppercase "T" above a square indicates that the experimenter tacted the relevant stimulus dimension previous to the first trial of that session.

A close examination of Figure 7 reveals that equalization was effective for increasing the frequency of correct responses to 16 (100%) from a wide range of baseline performances. For example, subject 16 during

Figure 7. Number of reinforced responses per session across all children. Conditions are separated by vertical lines with the element being trained labelled above each experimental condition. Blackened circles and squares denote stimulus equalization.



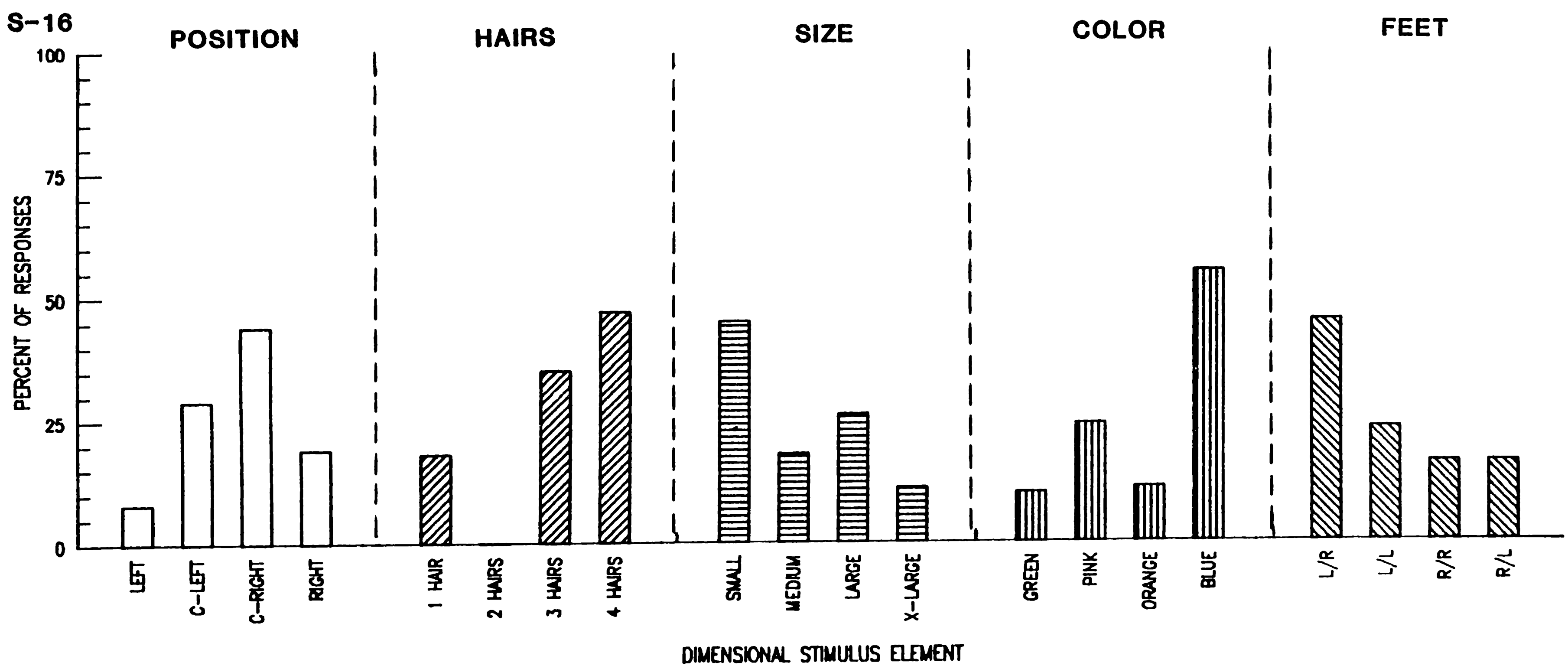
S-16
two hairs
small
green
L/R feet
S-17
t.h.
L/R feet
green
small
two hairs
LEGEND
ALL 16 TRIALS
LAST 8 TRIALS
S-22
two hairs
small
green
L/R
t.h.
green
S-23
two hairs
small
green
L/R feet
t.h.
green
sm.
L/R feet
S-24
two hairs
small
GR
NUMBER OF RESPONSES TO REINFORCED ELEMENT
SESSIONS

session one to session five (trial eight) was correctly responding on 33 percent of the trials. An analysis of the errors that occurred previous to stimulus equalization is shown in Figure 8 as the percent of incorrect responses (ordinate) to each of the stimulus elements (abscissa). The figure indicates that 44 percent (27) of the 62 incorrect responses were to the center-right screen position, 47 percent (29) were to the stimulus with four hairs, 45 percent (28) were to the small stimulus, 55 percent (34) were to the blue stimulus, and 45 percent (28) were incorrect responses to the stimulus with left-right feet. However, during the last half of session five subject 16 responded correctly to seven of the last eight trials and maintained a frequency of 100% correct responding over the next several sessions until the experimental condition was changed.

From session 28 (trial nine) to session 38 (trial eight), subject 22 was correctly responding over 60% of the time. Figure 9 presents an analysis of the errors that occurred. Eighty percent (52) of the 65 errors during this period were to the small stimulus. Before stimulus equalization occurred on session 38 (trial nine) subject 22's frequency of correct responding never reached 100% however from session 38 (trial nine) to the contingency change after session 44 (trial

Figure 8. Percentage of incorrect responses of subject 16 to each of the 16 stimulus elements and four positions.

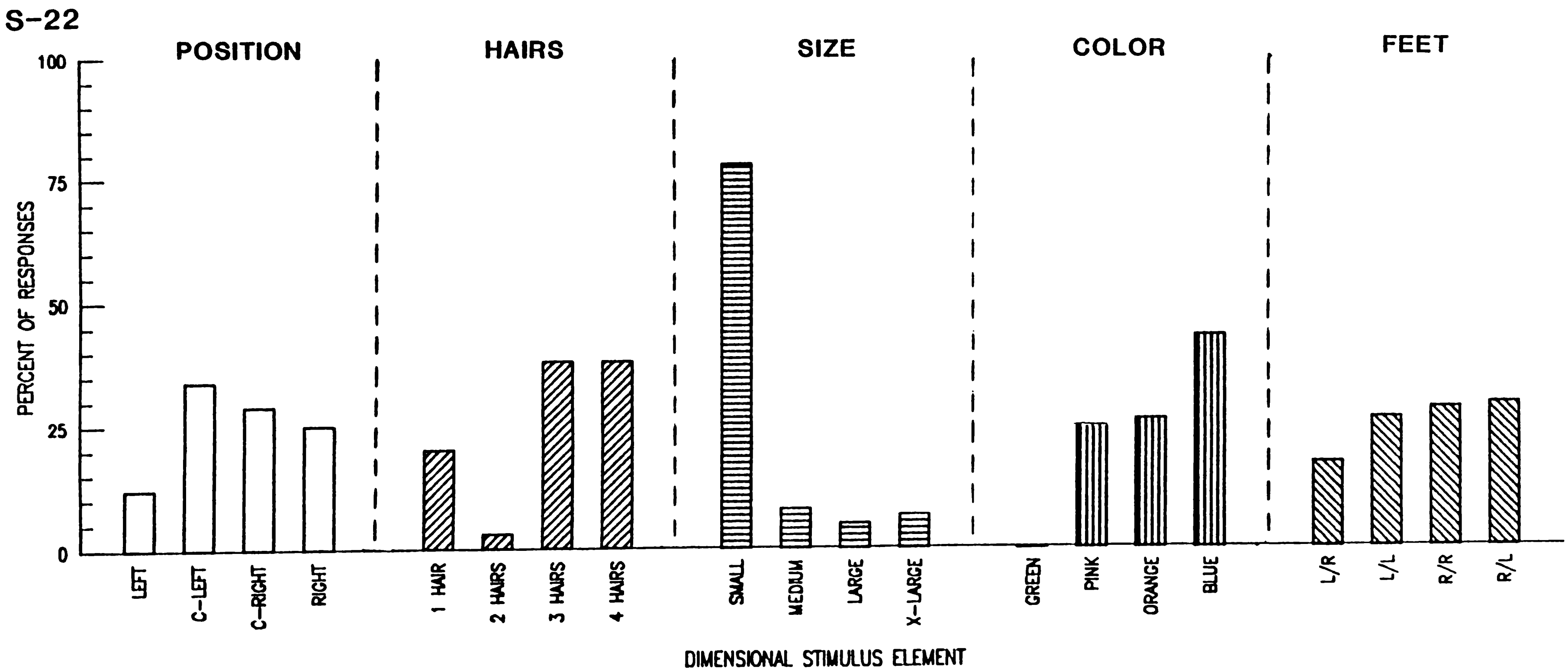
ERRORS DURING UNSUCCESSFUL TRIAL & ERROR TRAINING OF TWO HAIRS★



★these data are the 62 errors which occurred between session 1 (trial 1) and session 6 (trial 8) of S-16.

Figure 9. Percentage of incorrect responses of subject 22 to each of the 16 stimulus elements and four positions

ERRORS DURING UNSUCCESSFUL TRIAL & ERROR TRAINING OF GREEN★



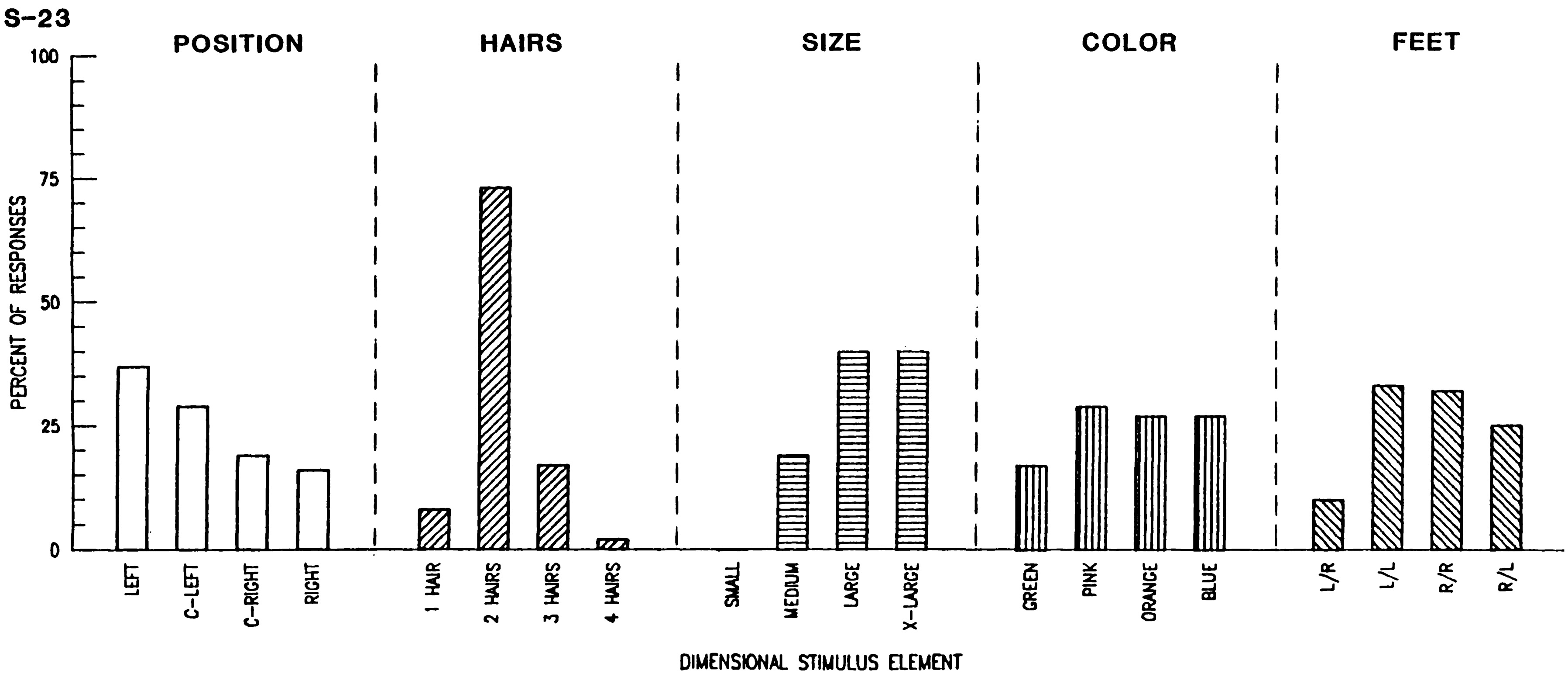
★these data are the 65 errors which occurred between session 28 (trial 9) and session 32 (trial 8) of S-22.

eight) subject 22 responded incorrectly only one time.

Stimulus equalization was also effective in bringing about 100% correct responding from a baseline of 0% correct responding. The reinforcement contingency was changed for subject 23 from two hairs to small on session 15 (trial nine) and 63 of the next 64 responses were incorrect. Figure 10 presents an analysis of those errors. Seventy three percent (46) of the 63 errors were to the stimulus with two hairs and 37% (23) of the incorrect responses were to the left screen position. Stimulus equalization occurred on session 19 (trial nine) and subject 23 responded correctly 50% of the time during the last half of this session. Only a single incorrect response was made from session 20 to session 25 (trial eight) when the experimental condition was changed. During one experimental condition of each of three different subjects (subject 16, subject 17, subject 24) tacting was used in addition to stimulus equalization. Figure 7 shows that the relevant dimension was tacted during the first trial of session 44, session 46, and session 47 of subject 16 after 120 trials of equalization training. The responses that occurred during that period of unsuccessful equalization training are portrayed on Figure 11 as the percent of total responses (ordinate) of subject 16 to each of the

Figure 10. Percentage of incorrect responses of subject 23 to each of the 16 stimulus elements and four positions

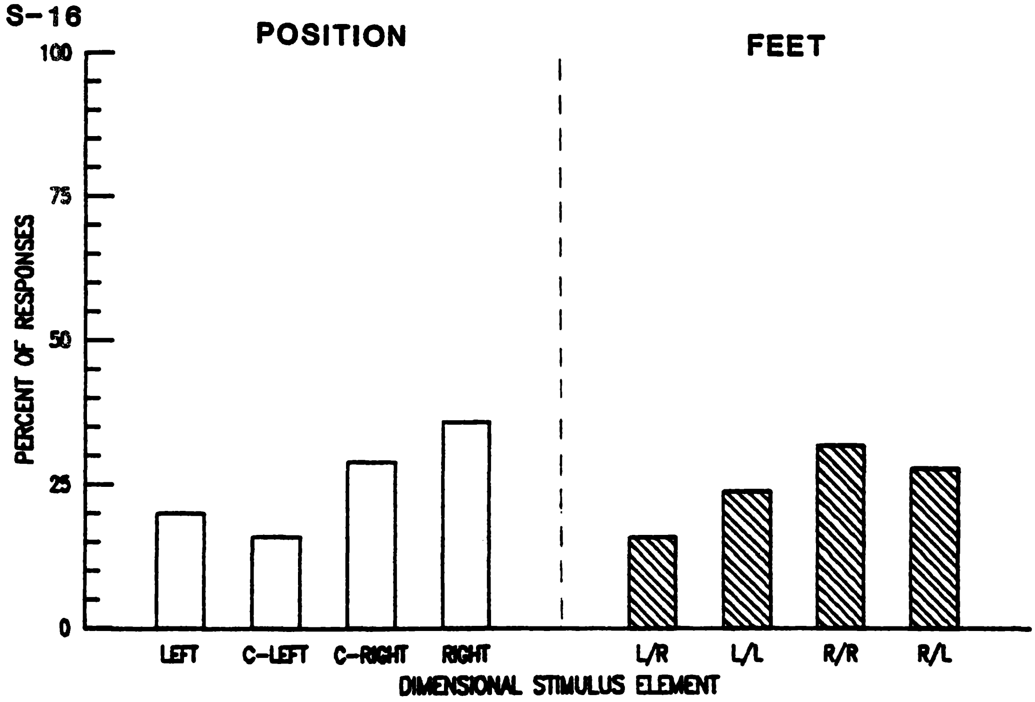
ERRORS DURING UNSUCCESSFUL TRIAL & ERROR TRAINING OF SMALL★



★these data are the 63 errors which occured between session 15 (trial 9) and session 19 (trial 8) of S-23.

Figure 11. Percentage of responses to unequalized stimulus dimensions of subject 16 during equalization training of a feet discrimination.

RESPONSES DURING UNSUCCESSFUL EQUALIZATION TRAINING OF LEFT-RIGHT FEET★



★these data are responses of S-16 from session 36 (trial 9) to session 46 (trial 8).

elements along the unequalized stimulus dimensions (position and feet). The figure shows that 36 percent (57) of the 120 responses were to the right screen position and 32 percent (51) were to the stimulus with right-right feet. Only a single error occurred (session 48, trial one) from trial nine of session 47 to the conclusion of the experimental condition after session 49.

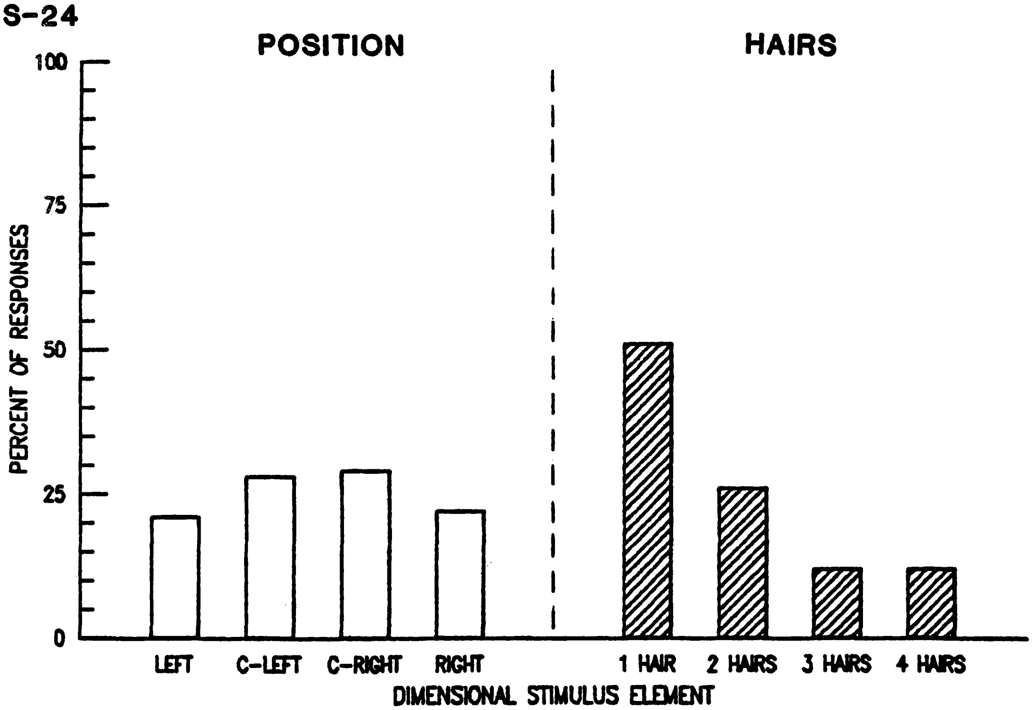
A tact also occurred for subject 17 on trial one of session nine. Only two errors occurred subsequent to the initial tacting (the first trial of sessions nine and 10) before the condition ended after trial eight of session 14.

Two consecutive tacts occurred on the first trial of sessions 13 and 14 after 104 trials during which stimulus equalization occurred but was not successful. Figure 12 shows that subject 24 responded to the stimulus with one hair on 51 percent (61) of those trials. A string of 90 consecutive correct responses occurred to end the experimental condition starting with trial 15 of session 13.

Differences in irrelevant stimulus dimensions (stimulus complexity) were immediately reinstated on trial nine of a session which began with the stimuli being equalized during the first eight trials. Immediate reinstatement of stimulus complexity was

Figure 12. Percentage of responses to unequalized stimulus dimensions of subject 24 during equalization training of a hairs discrimination.

RESPONSES DURING UNSUCCESSFUL EQUALIZATION TRAINING OF TWO HAIRS*



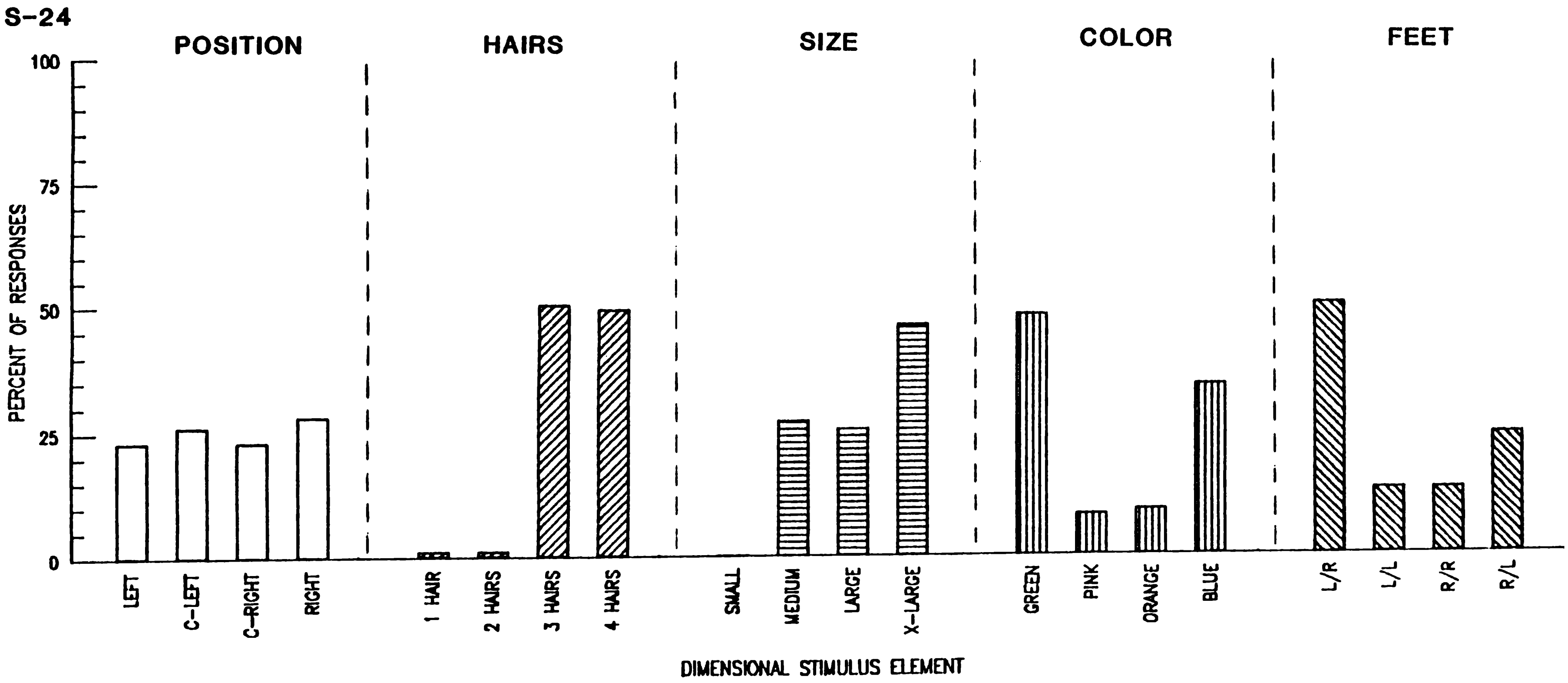
*these data are the responses of S-24 from session 6 (trial 9) to session 13 (trial 16).

attempted in each of the 14 experimental conditions during which stimulus equalization and/or tacting occurred. Errors occurred subsequent to immediate reinstatement of stimulus complexity during only four of the 14 conditions (see Figure 7); one error occurred in two of those conditions (subject 16 session 22, and subject 22 session 42), two errors occurred in one condition (subject 22 sessions 25 and 26), and several errors occurred during the second experimental condition of subject 24.

For the second experimental condition of subject 24, stimulus equalization and subsequent immediate reinstatement of stimulus complexity was attempted twice with numerous errors occurring each time (see Figures 7 and 13). Subsequent to the third stimulus equalization period, gradual reinstatement of stimulus complexity was attempted. Gradual equalization involved reinstating dimensional differences one dimension at a time instead of all at once as in immediate reinstatement. Figure 14 shows the manner in which the stimuli were gradually reinstated as well as the number of correct responses for successive blocks of eight trials between sessions 42 and 54 of subject 24. The figure indicates that 100% correct responding occurred only when the dimension of color was equalized. When color differences in the stimuli were

Figure 13. Percentage of incorrect responses of subject 24 to each of the 16 stimulus elements and four positions.

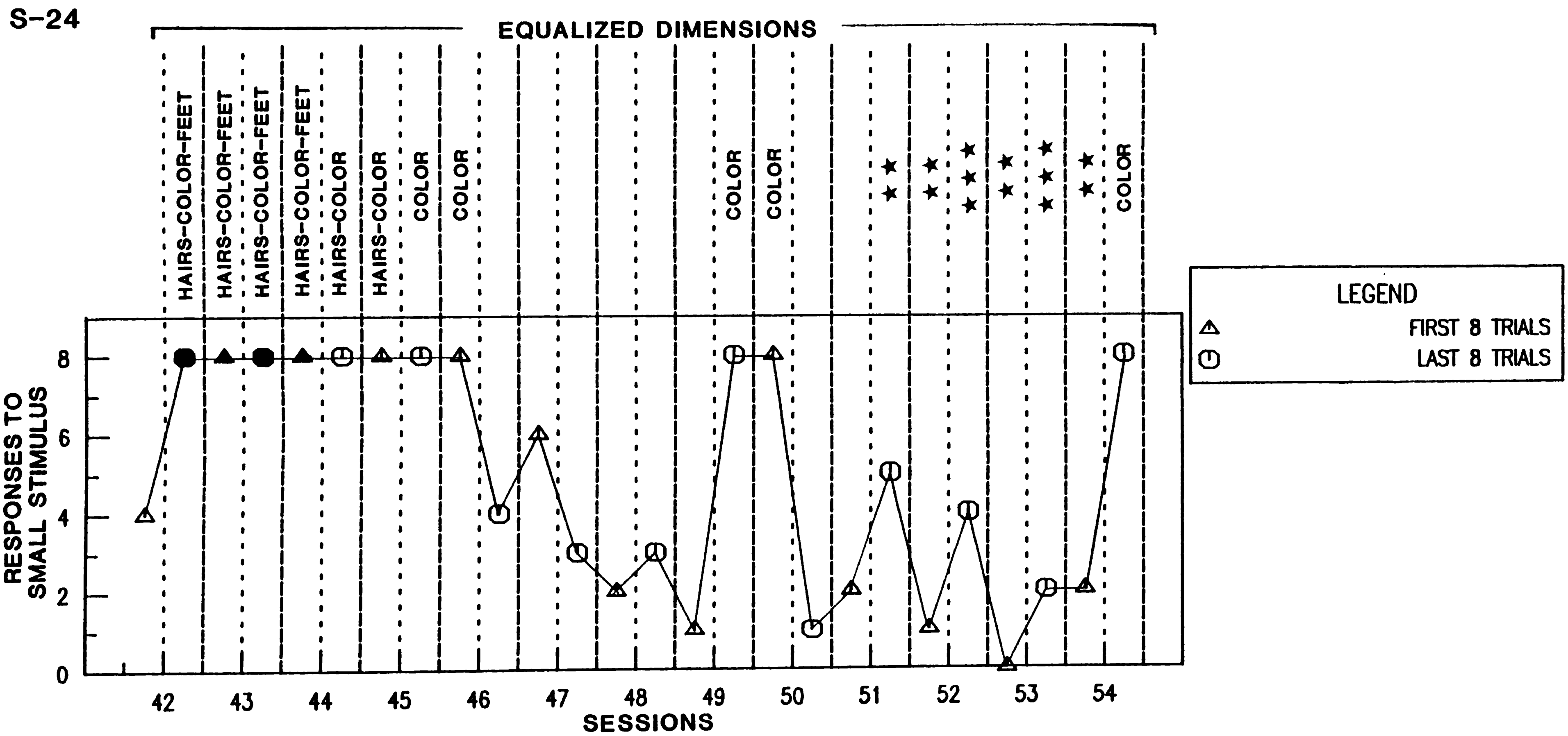
ERRORS DURING UNSUCCESSFUL EQUALIZATION TRAINING OF SMALL★



★these data are the 149 errors which occurred between session 29 (trial 9) and session 51 (trial 8) of S-24.

Figure 14. Number of responses to the small stimulus (reinforced) before, during, and after gradual reinstatement of stimulus complexity for subject 24. Equalized dimensions are shown on the top horizontal plane for each half-session.

GRADUAL REINSTATEMENT OF STIMULUS COMPLEXITY DURING SIZE DISCRIMINATION



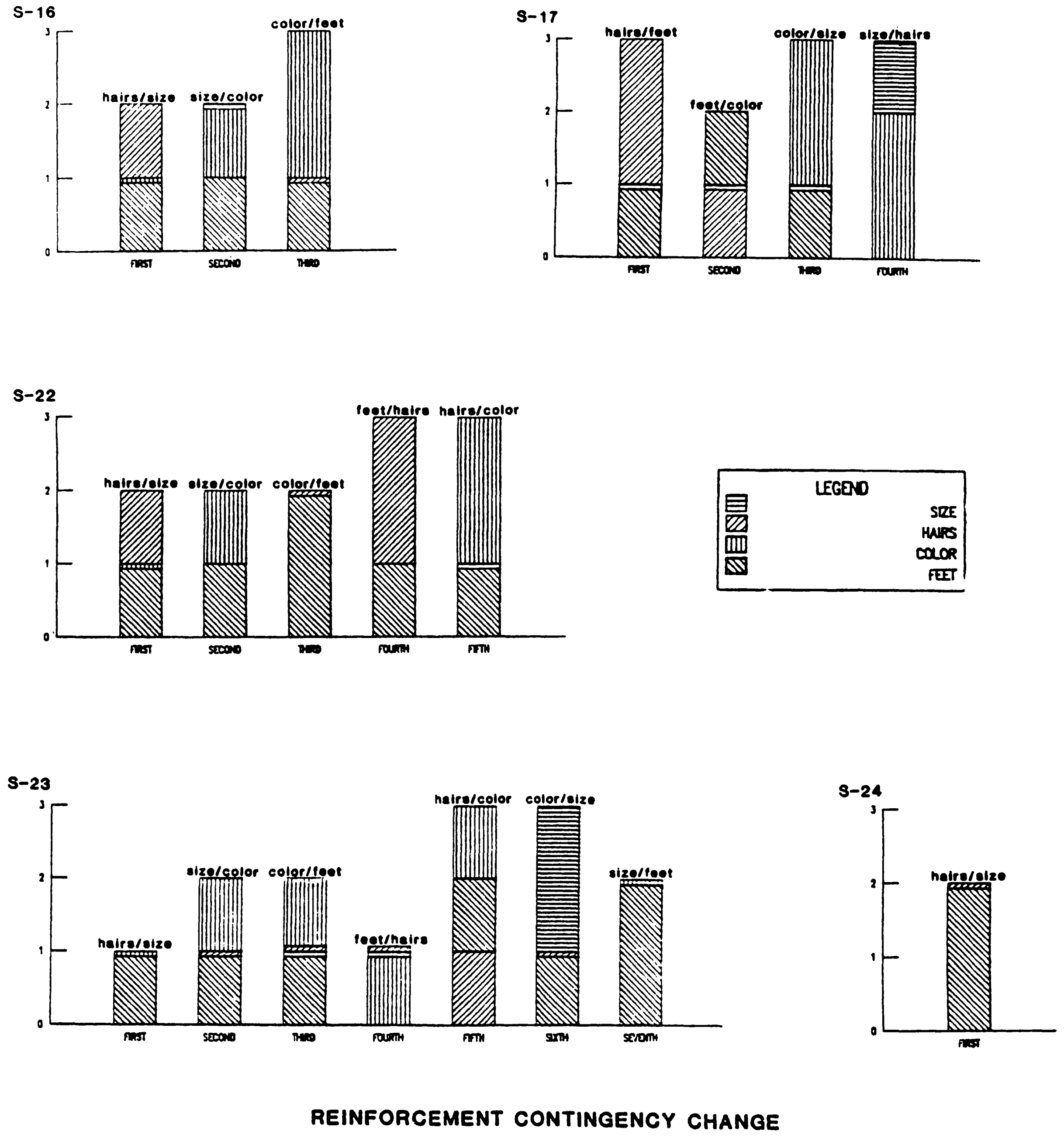
★ ★ size dimension involves two elements (small-X large)

★ ★ ★ size dimension involves three elements (small-large-X large) present, correct responding decreased.

Contingency changes occurred between the eighth and ninth trial of a given session dependent upon the child correctly responding four times during trials four through eight of that particular session. Both correct and incorrect responses occurred subsequent to those changes in the reinforcement contingency. Figure 15 is an illustration of dimensional similarity between subjects' correct responses (contacts with reinforcement) subsequent to contingency changes and immediately subsequent responses. For example, if the contingency was switched from two hairs to left-right feet after the eighth trial of a session an error would occur on following trials. When reinforcement is again contacted, the selected stimulus might be one-haired, small, and blue with right-right feet. If, on the following trial, the stimulus had one hair, was medium sized, and had right-right feet the subject's response would be consistent with respect to the hairs and feet dimensions. Figure 15 portrays the number of dimensional consistencies that occurred (ordinate) for each of the contingency changes (abscissa). Previously relevant stimulus dimensions are printed to the left of the slash located at the top of each bar while currently relevant dimensions are printed to the right of the slash. The figure indicates that for subject 17

Figure 15. Number of dimensional consistencies following three initial contacts with reinforcement subsequent to contingency changes.

DIMENSIONAL SIMILARITY BETWEEN INITIAL CONTACTS WITH REINFORCEMENT AND SUBSEQUENT RESPONSES



the first three contacts with reinforcement subseqent to the first contingency change (from hairs to feet) were followed by responses consistent with the hairs dimension three times and with the size and feet dimensions only once. No dimensional consistency was found with respect to the color. As shown in Figure 15, dimensional consistency with the previously relevant dimension occurred most or as often as consistency with any other stimulus dimension (i.e., subjects tended to respond to the dimension that had previously been relevant). For three subjects, (subject 16, subject 17, and subject 24) this was true of all contingency changes.

Discussion

The results of this study show that stimulus equalization is an effective teaching procedure for young children who are having difficulty acquiring visual discriminations through trial-and-error training. In most cases (from a variety of baseline levels), visual discriminations were quickly facilitated when differences along irrelevant stimulus dimensions were eliminated. When correct responding was stable, differences along irrelevant dimensions were immediately reinstated without error in most cases.

These results are consistent with earlier findings concerning dimensional complexity (Granzin & Carnine, 1977; House & Zeaman, 1960; Pomerantz & Garner, 1973) and extend the importance of those findings by incorporating them into an effective teaching procedure. The failure of children to acquire visual discriminations involving multidimensional stimuli through trial-and-error training may be due to their not responding to the dimension of the stimuli upon which the discrimination is based (Zeaman & House, 1963). For example, a child may be looking at the color of the stimuli rather than the shape during a shape discrimination task. The success of the stimulus equalization procedure may be explained in that the child (as when tacted) is being directed to look at the relevant stimulus dimension. Once the child is responding to the dimension upon which the discrimination is based, contact with the reinforcement contingency is sufficient to promote correct responding.

The response analysis performed by the computer proved effective for identifying sources of inappropriate stimulus control during training of visual discriminations. Some of the types of inappropriate stimulus control identified in the present study included responses restricted to a certain position or positions, responses consistent with an element not correlated with or only partially correlated with reinforcement, and conditional control by two or more of these factors (e.g., responses to the character with the least number of hairs of the two located on the left portion of the screen).

Once inappropriate stimulus control has been identified, the computer could implement procedures to disrupt such control and direct the student to look at the stimulus characteristics critical to the discrimination task. For example, if a subject was consistently responding to the size of the stimuli rather than the number of hairs, the computer might equalize the size dimension and/or emphasize the hairs dimension by flashing the hairs of all the characters or performing some other stimulus manipulation aimed at directing the child to look at the relevant dimension. When the child was responding appropriately to two hairs, the computer could reverse the manipulations performed earlier. If a child responded appropriately to some stimulus element only when the dimension of color was equalized, color differences might be slowly faded in until the child was correctly responding to stimuli with full color differences. Using a properly constructed response analysis, the possiblilites for computer-initiated interventions during an instructional program are as numerous as the types of inappropriate stimulus control which might develop.

An analysis of the errors that occurred immediately subsequent to contingency changes suggested that subjects responded most often to elements of the dimension previously trained than to elements of other stimulus dimensions. This finding is consistent with the abundant literature on intradimensional versus extradimensional shifts (Esposito, 1975) and may be an important consideration for the development of educational software.

In conclusion, results of this study indicate that computer-based stimulus equalization was a practical and effective procedure for facilitating visual discrimination training of preschool children. The response analysis performed by the computer was beneficial in understanding errors which occur during learning and may subsequently lead to the development of procedures for correcting individual learning problems through timely, brief, computer-initiated interventions.

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Author Notes

This research was begun in June of 1982 when I arrived at Kansas. The first few months were spent becoming familiar with the APPLE II microcomputer (a wonderful machine!) and from September, 1982 to September, 1983 several preliminary studies were conducted to work out program bugs and finalize the procedure we have termed "Stimulus Equalization." The present study was conducted in the Fall of 1983. I would like to extend my gratitude to all of the children who participated in this project, and to their parents and teachers for their kind cooperation.

To recieve a reprint of this manuscript or information concerning the computer programs used in the conduct of this research please contact:

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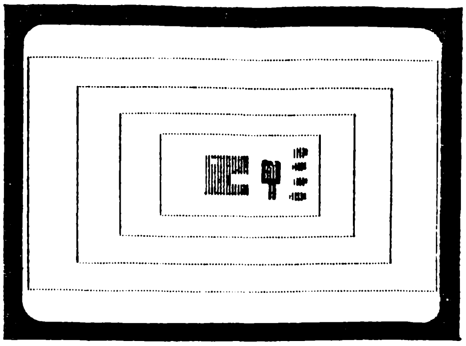
Human Development and Family life
130 Haworth Hall - University of Kansas
Lawrence, Kansas 66045
(913) 864-4840

Appendix A

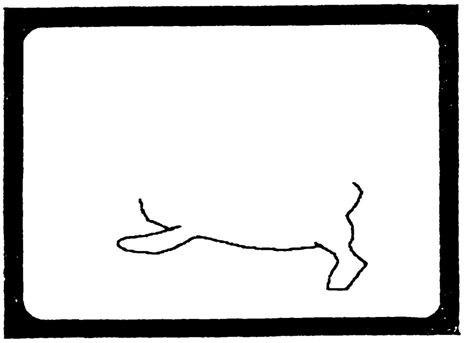
Example of an audio/graphics routine used as a potential back-up reinforcer. A short tune occurred at steps one and six.

AN EXAMPLE OF AN AUDIO/GRAPHICS ROUTINE

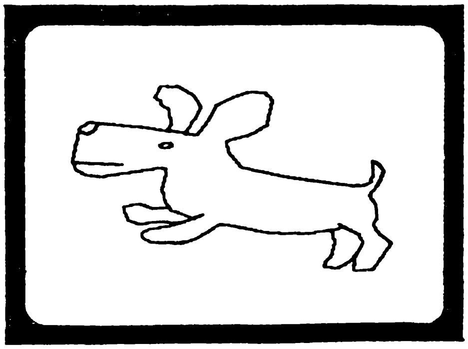
Step 1



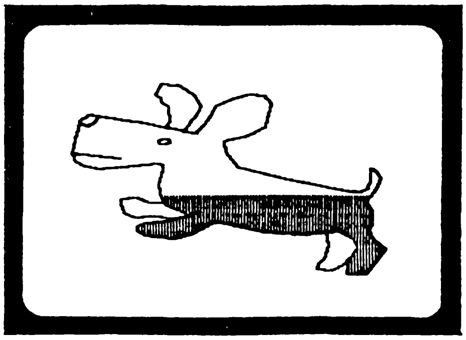
Step 2



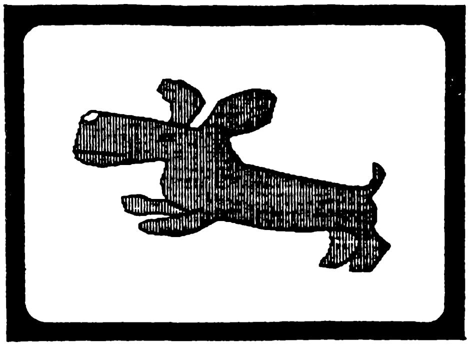
Step 3



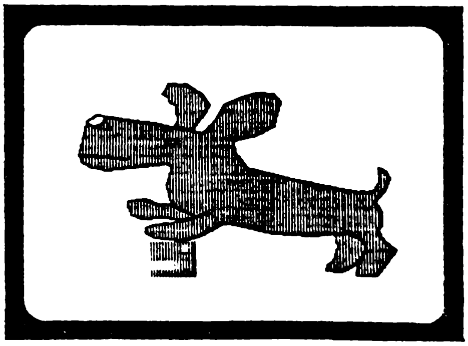
Step 4



Step 5



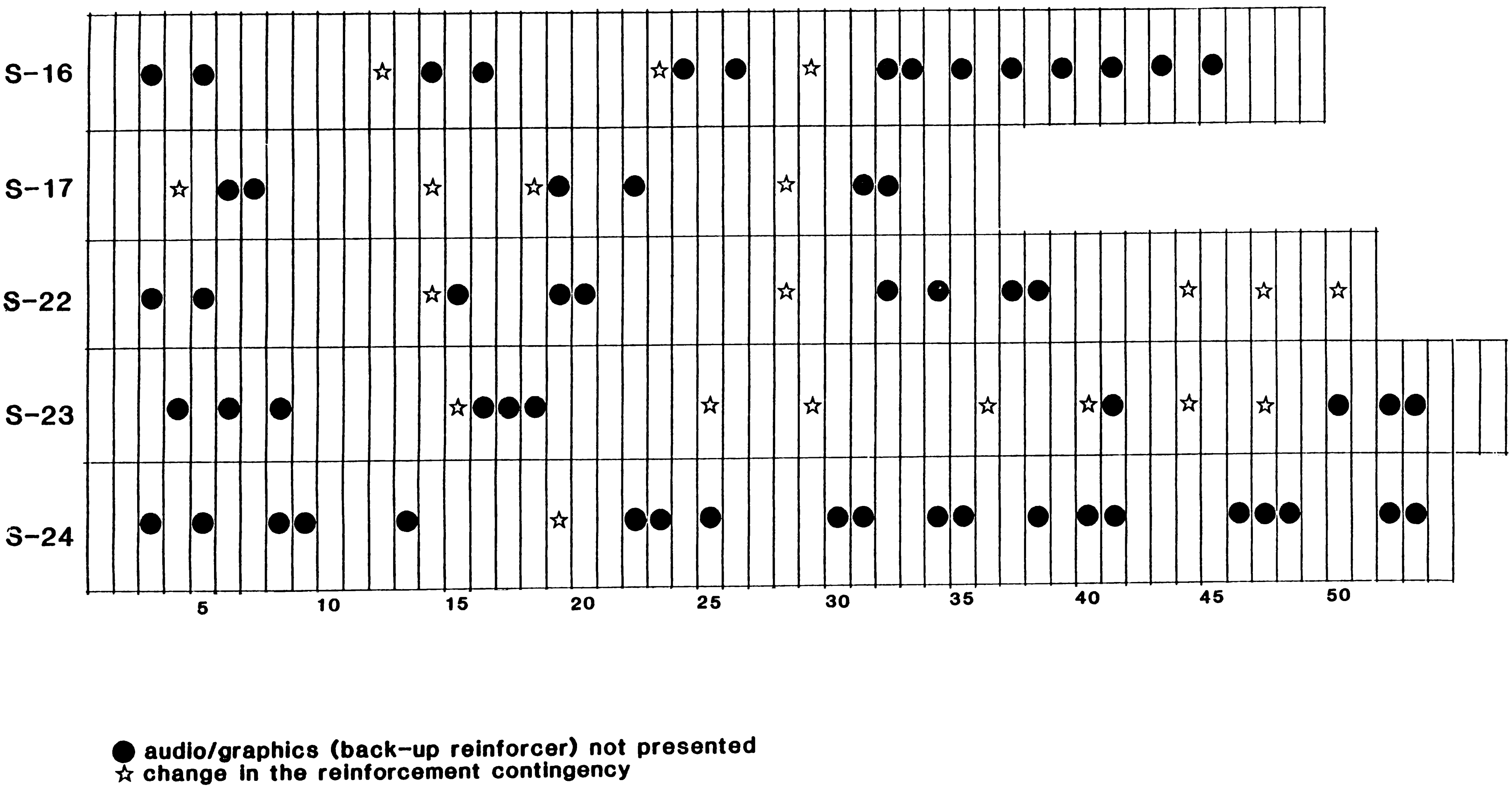
Step 6



Appendix B

Graphic depiction of the occurrence and non-occurrence of the audio/graphics routine for all children.

EXPERIMENTAL SESSIONS ENDING WITHOUT
PRESENTATION OF AUDIO/GRAPHICS ROUTINE



Appendix C

An example of a data sheet printed by the computer following an experimental session. The response analysis grid is located in the lower half of the data sheet.

PROPERTY OF H.D.F.L. DEPT. - UNIVERSTIY OF KANSAS

RESEARCHERS: J. AARON HOKO & JUDITH M. LEBLANC
STUDY: TOPOGRAPHIES OF STIMULUS CONTROL
EXPERIMENT: A MICROCOMPUTER ANALYSIS OF PRESCHOOL CHILDREN'S PROBLEM SOLVING

ROBERT S-16 SESS #4 9/15/83 HAIRS<6> TC=4 EC=1 QC=3 S-SET=1

TRIAL	PS+?	STIM. DISPLAY (H-S-C-F)				C	RESPONSE	LATENCY
1	4213	53110	-----	7459	62611	0	8-1-2-12	19.1891892
2	1324	62512	74111	-----	5329	0	8-1-6-10	7.02702703
3	3142	71611	5259	-----	84110	1	6-3-2-12	12.2972973
4	2431	-----	63610	52111	71512	0	8-4-2-9	6.89189189
5	4123	51510	82112	-----	64211	0	7-3-6-9	17.027027
6	2341	8269	64510	-----	73112	0	5-1-2-11	8.91891892
7	3412	74111	5329	62512	-----	0	8-1-6-10	7.43243243
8	1234	63212	-----	84110	5259	0	7-1-6-11	9.5945946
9	3421	7459	53110	-----	81212	1	6-2-6-11	7.56756757
10	1243	-----	71512	8429	52111	1	6-3-6-10	12.972973
11	4132	51211	-----	73112	64510	0	8-2-6-9	6.35135135
12	2314	82112	64211	51510	-----	0	7-3-6-9	13.5135135
13	4231	5329	-----	74111	62512	0	8-1-6-10	16.0810811
14	3124	71512	52111	-----	8429	1	6-3-6-10	11.7567568
15	1342	-----	7459	81212	53110	1	6-2-6-11	16.8918919
16	2413	84110	63212	5259	-----	0	7-1-6-11	9.18918919

\# 'CORRECT' RESP.=5 MEAN LATENCY=11.4189189 SEC
PC 'CORRECT' RESP.=31.25% MEDIAN LATENCY=10.6756757 SEC

INTERQUARTILE LATENCY RANGE= 7.5 TO 14.7972973 SEC
TOTAL LATENCY RANGE= 6.35135135 TO 19.1891892 SEC

RESPONSE ANALYSIS GRID

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	#	PC
LEFT POSITION	-	-	-	X	-	-	-	-	-	X	-	-	-	-	X	-	3	18.75
C-LEFT POSITION	X	-	-	-	-	-	-	X	-	-	X	-	X	-	-	-	4	25
C-RIGHT POSITION	-	X	X	-	X	X	-	-	X	-	-	-	-	X	-	-	6	37.5
RIGHT POSITION	-	-	-	-	-	-	X	-	-	-	-	X	-	-	-	X	3	18.75
ONE HAIR	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	1	6.25
TWO HAIRS	-	-	X	-	-	-	-	-	X	X	-	-	-	X	X	-	5	31.25
THREE HAIRS	-	-	-	-	X	-	-	X	-	-	-	X	-	-	-	X	4	25
FOUR HAIRS	X	X	-	X	-	-	X	-	-	-	X	-	X	-	-	-	6	37.5
SMALL SIZE	X	X	-	-	-	X	X	X	-	-	-	-	X	-	-	X	7	43.75
MEDIUM SIZE	-	-	-	-	-	-	-	-	X	-	X	-	-	-	X	-	3	18.75
LARGE SIZE	-	-	X	-	X	-	-	-	-	X	-	X	-	X	-	-	5	31.25
EXTRA-LARGE SIZE	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	1	6.25
GREEN COLOR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
PINK COLOR	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-	-	4	25
ORANGE COLOR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
BLUE COLOR	-	X	-	-	X	-	X	X	X	X	X	X	X	X	X	X	12	75
LEFT/RIGHT FEET	-	-	-	X	X	-	-	-	-	-	X	X	-	-	-	-	4	25
LEFT/LEFT FEET	-	X	-	-	-	-	X	-	-	X	-	-	X	X	-	-	5	31.25
RIGHT/RIGHT FEET	-	-	-	-	-	X	-	X	X	-	-	-	-	-	X	X	5	31.25
RIGHT/LEFT FEET	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	2	12.5

TRIALS

Appendix D

An example of a recording sheet used by the experimenter. Letters represent verbalizations, numbers indicate response location, and a + or - denotes the presence or absence of reinforcement.

Study # 5 S- 16

Data (or) Reliability Name ____________

Sessions

Trial	1	2	3	4	5	6	7	8	9	10	11	12	13
1	D 3- N	D 4- N	D 3+	D 2- N	W 1-	3+	4+ P	3+	3+ P	4+ PD	3+	3+ WD	4-
2	3-	2+	1+	3-	1-	W 1+	1+	2+	W 1+ D	1+	2+	1+ P	4-
3	3+ P	2-	3-	3+	3- N	2-	3+ PD	D 1+	++	W 3+ P	D 1+ P	4+	3- W D
4	1-	3-	4-	1-	4+	4- N	2+	4+ P	2+	2+	4+	2+ E	4+
5	3-	W 3-	2-	3-	1- N	2- N	4+	D 2+	4+ P	D 4-	2+	4+	3-
6	4-	3-	4-	3-	3-	3+	D 2+	4+	3+	2+	4+	3+	2-
7	3+	2-	3-	4-	4-	1+	3+	3+	1+	3+	3+ D	1+	1-
8	4-	2-	2+	2-	2-	2+	W 1+ P	1+ P	2+	1+ P	1+	2+	2+ W
9	3+	3-	2-	3+ P	2-	3+	3+	4+ D	3+	3+	4+	3-	1-
10	1+	3-	2+	1+	3-	3-	1+	1+	2+	1+	1+	2-	2+
11	2-	3+ P	3-	2-	3+ P	1+	4+	3+	1+ P	4- D	3+	1- N	3-
12	3-	2+	2-	4-	2+	4+	2+	2+ P	4+	2+	P 2+	D 4-	2-
13	2-	3-	3-	2-	3-	2+ P	4+ P	4+	2+	4+	4+ D	2- N	4-
14	3+	3-	3-	3+ P	3-	4+	3+	D 2+	4+	3+	2+	4-	W 3-
15	1+	P 2-	4-	1+	4-	3+	1+	3+	3+	1+	3+	2+	2-
16	3-	3-	3-	4-	2-	1+	2+	1+ E	1+	2+	1+	1-	2-