CHAPTER 6

Constructing and Interpreting Graphic Displays of Behavioral Data

Key Terms

bar graph
cumulative record
cumulative recorder
data
data path
dependent variable
graph
independent variable
level
line graph
local response rate
overall response rate
scatterplot
semilogarithmic chart
split-middle line of progress
Standard Celeration Chart
trend
variability
visual analysis

Behavior Analyst Certification Board® BCBA® & BCABA® Behavior Analyst Task List ©, Third Edition

	Content Area 7: Displaying and Interpreting Behavioral Data
7-1	Select a data display that effectively communicates quantitative relations.
7-2	Use equal-interval graphs.
7-3	Use Standard Celeration Charts (for BCBA only—excluded for BCABA).
7-4	Use a cumulative record to display data.
7-5	Use data displays that highlight patterns of behavior (e.g., scatterplot).
7-6	Interpret and base decision making on data displayed in various formats.

Applied behavior analysts document and quantify behavior change by direct and repeated measurement of behavior. The product of these measurements, called **data,** is the medium with which behavior analysts work. In everyday usage the word *data* refers to a wide variety of often imprecise and subjective information offered as facts. In scientific usage the word *data* means "the results of measurement, usually in quantified form" (Johnston & Pennypacker, 1993a, p. 365).[1]

Because behavior change is a dynamic and ongoing process, the behavior analyst—the practitioner and the researcher—must maintain direct and continuous contact with the behavior under investigation. The data obtained throughout a behavior change program or a research study are the means for that contact; they form the empirical basis for every important decision: to continue with the present procedure, to try a different intervention, or to reinstitute a previous condition. But making valid and reliable decisions from the raw data themselves (a series of numbers) is difficult, if not impossible, and inefficient. Inspecting a long row of numbers will reveal only very large changes in performance, or no change at all, and important features of behavior change can easily be overlooked.

Consider the three sets of data that follow; each consists of a series of numbers representing consecutive measures of some target behavior. The first data set shows the results of successive measures of the number of responses emitted under two different conditions (A and B):

Condition A	**Condition B**
120, 125, 115, 130,	114, 110, 115, 121,
126, 130, 123, 120,	110, 116, 107, 120,
120, 127	115, 112

Here are some data showing consecutive measures of the percentage of correct responses:

80, 82, 78, 85, 80, 90, 85, 85, 90, 92

The third data set consists of measures of responses per minute of a target behavior obtained on successive school days:

65, 72, 63, 60, 55, 68, 71, 65, 65, 62, 70, 75, 79, 63, 60

What do these numbers tell you? What conclusions can you draw from each data set? How long did it take you to reach your conclusions? How sure of them are you? What if the data sets contained many more measures to interpret? How likely is it that others interested in the behavior change program or research study would reach the same conclusions? How could these data be directly and effectively communicated to others?

Graphs—relatively simple formats for visually displaying relationships among and between a series of measurements and relevant variables—help people "make sense" of quantitative information. Graphs are the major device with which applied behavior analysts organize, store, interpret, and communicate the results of their work. Figure 6.1 includes a graph for each of the three data sets presented previously. The top graph reveals a lower level of responding during Condition B than during Condition A. The middle graph clearly shows an upward trend

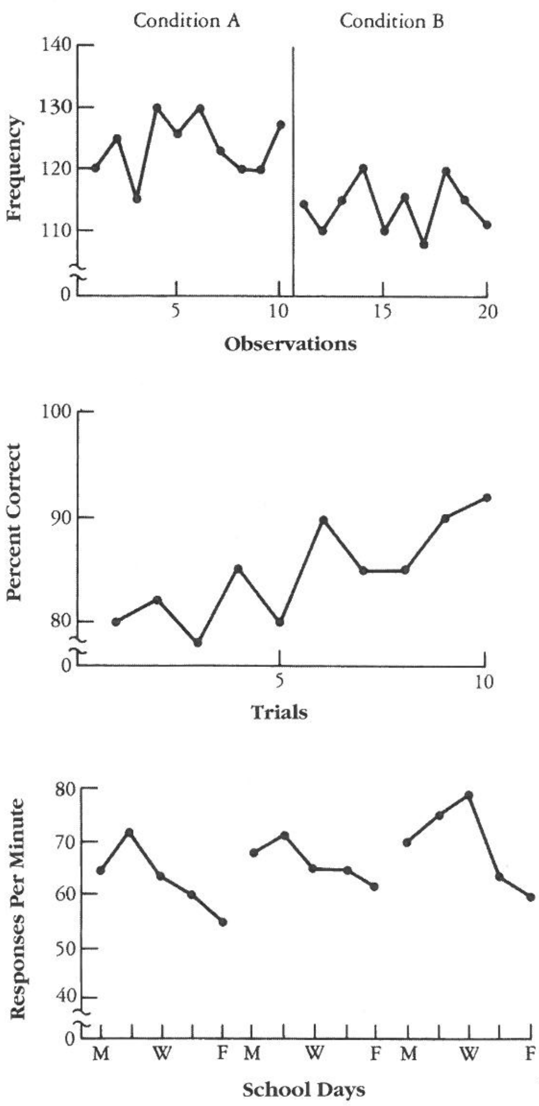

Figure 6.1 Graphic displays of three sets of hypothetical data illustrating changes in the level of responding across conditions (top), trend (middle), and cyclical variability (bottom).

[1]Although often used as a singular construction (e.g., "The data *shows* that . . ."), *data* is a plural noun of Latin origin and is correctly used with plural verbs (e.g., "These data *are* . . .").

over time in the response measure. A variable pattern of responding, characterized by an increasing trend during the first part of each week and a decreasing trend toward the end of each week, is evident in the bottom graph. The graphs in Figure 6.1 illustrate three fundamental properties of behavior change over time—level, trend, and variability—each of which will be discussed in detail later in the chapter. The graphic display of behavioral data has proven an effective means of detecting, analyzing, and communicating these aspects of behavior change.

Purpose and Benefits of Graphic Displays of Behavioral Data

Numerous authors have discussed the benefits of using graphs as the primary vehicle for interpreting and communicating the results of behavioral treatments and research (e.g., Baer, 1977; Johnston & Pennypacker, 1993a; Michael, 1974; Parsonson, 2003; Parsonson & Baer, 1986, 1992; Sidman, 1960). Parsonson and Baer (1978) said it best:

> In essence, the function of the graph is to communicate, in a readily assimilable and attractive manner, descriptions and summaries of data that enable rapid and accurate analysis of the facts. (p. 134)

There are at least six benefits of graphic display and visual analysis of behavioral data. First, plotting each measure of behavior on a graph right after the observational period provides the practitioner or researcher with immediate access to an ongoing visual record of the participant's behavior. Instead of waiting until the investigation or teaching program is completed, behavior change is evaluated continually, allowing treatment and experimental decisions to be responsive to the participant's performance. Graphs provide the "close, continual contact with relevant outcome data" that can lead to "measurably superior instruction" (Bushell & Baer, 1994, p. 9).

Second, direct and continual contact with the data in a readily analyzable format enables the researcher as well as the practitioner to explore interesting variations in behavior as they occur. Some of the most important research findings about behavior have been made because scientists followed the leads suggested by their data instead of following predetermined experimental plans (Sidman, 1960, 1994; Skinner, 1956).

Third, graphs, like statistical analyses of behavior change, are judgmental aids: devices that help the practitioner or experimenter interpret the results of a study or treatment (Michael, 1974). In contrast to the statistical tests of inference used in group comparison research, however, visual analysis of graphed data takes less time, is relatively easy to learn, imposes no predetermined or arbitrary level for determining the significance of behavior change, and does not require the data to conform to certain mathematical properties or statistical assumptions to be analyzed.

Fourth, visual analysis is a conservative method for determining the significance of behavior change. A behavior change deemed statistically significant according to a test of mathematical probabilities may not look very impressive when the data are plotted on a graph that reveals the range, variability, trends, and overlaps in the data within and across experimental or treatment conditions. Interventions that produce only weak or unstable effects are not likely to be reported as important findings in applied behavior analysis. Rather, weak or unstable effects are likely to lead to further experimentation in an effort to discover controlling variables that produce meaningful behavior change in a reliable and sustained manner. This screening out of weak variables in favor of robust interventions has enabled applied behavior analysts to develop a useful technology of behavior change (Baer, 1977).[2]

Fifth, graphs enable and encourage independent judgments and interpretations of the meaning and significance of behavior change. Instead of having to rely on conclusions based on statistical manipulations of the data or on an author's interpretations, readers of published reports of applied behavior analysis can (and should) conduct their own visual analysis of the data to form independent conclusions.[3]

Sixth, in addition to their primary purpose of displaying relationships between behavior change (or lack thereof) and variables manipulated by the practitioner or researcher, graphs can also be effective sources of feedback to the people whose behavior they represent (e.g., DeVries, Burnettte, & Redmon, 1991; Stack & Milan, 1993). Graphing one's own performance has also been demonstrated to be an effective intervention for a variety of academic and behavior change objectives (e.g., Fink & Carnine, 1975; Winette, Neale, & Grier, 1979).

Types of Graphs Used in Applied Behavior Analysis

Visual formats for the graphic display of data most often used in applied behavior analysis are line graphs, bar graphs, cumulative records, semilogarithmic charts, and scatterplots.

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[2]A comparison of the visual analysis of graphed data and inferences based on statistical tests of significance is presented in Chapter 10.

[3]Graphs, like statistics, can also be manipulated to make certain interpretations of the data more or less likely. Unlike statistics, however, most forms of graphic displays used in behavior analysis provide direct access to the original data, which allows the inquisitive or doubtful reader to regraph (i.e., manipulate) the data.

Line Graphs

The simple **line graph,** or frequency polygon, is the most common graphic format for displaying data in applied behavior analysis. The line graph is based on a Cartesian plane, a two-dimensional area formed by the intersection of two perpendicular lines. Any point within the plane represents a specific relationship between the two dimensions described by the intersecting lines. In applied behavior analysis, each point on a line graph shows the level of some quantifiable dimension of the target behavior (i.e., the **dependent variable**) in relation to a specified point in time and/or environmental condition (i.e., the **independent variable**) in effect when the measure was taken. Comparing points on the graph reveals the presence and extent of changes in level, trend, and/or variability within and across conditions.

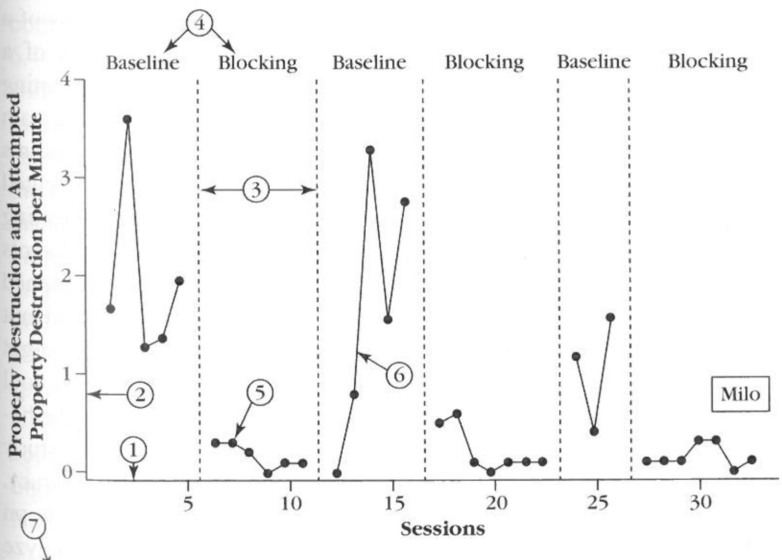
Parts of a Basic Line Graph

Although graphs vary considerably in their final appearance, all properly constructed line graphs share certain elements. The basic parts of a simple line graph are shown in Figure 6.2 and described in the following sections.

1. Horizontal Axis. The *horizontal axis,* also called the x *axis,* or *abscissa,* is a straight horizontal line that most often represents the passage of time and the presence, absence, and/or value of the independent variable. A defining characteristic of applied behavior analysis is the repeated measurement of behavior across time. Time is also the unavoidable dimension in which all manipulations of the independent variable occur. On most line graphs the passage of time is marked in equal intervals on the horizontal axis. In Figure 6.2 successive 10-minute sessions during which the number of property destruction responses (including attempts) was measured are marked on the horizontal axis. In this study, 8 to 10 sessions were conducted per day (Fisher, Lindauer, Alterson, & Thompson, 1998).

The horizontal axis on some graphs represents different values of the independent variable instead of time. For example, Lalli, Mace, Livezey, and Kates (1998) scaled the horizontal axis on one graph in their study from less than 0.5 meters to 9.0 meters to show how the occurrence of self-injurious behavior by a girl with severe mental retardation decreased as the distance between the therapist and the girl increased.

2. Vertical Axis. The *vertical axis,* also called the y *axis,* or *ordinate,* is a vertical line drawn upward from the left-hand end of the horizontal axis. The vertical axis most often represents a range of values of the dependent variable, which in applied behavior analysis is always some quantifiable dimension of behavior. The intersection of the horizontal and vertical axes is called the *origin* and usually, though not necessarily, represents the zero value of the dependent variable. Each successive point upward on the vertical axis represents a greater value of the dependent variable. The most common practice is to mark the vertical axis with an equal-interval scale. On an *equal-interval vertical axis* equal distances on the axis represent equal amounts of behavior. The vertical axis in Figure 6.2 represents the number of property destruction responses (and attempts) per minute with a range of 0 to 4 responses per minute.



Rates of property destruction (plus attempts) during baseline and the blocking condition for Milo.

Figure 6.2 The major parts of a simple line graph: (1) horizontal axis, (2) vertical axis, (3) condition change lines, (4) condition labels, (5) data points, (6) data path, and (7) figure caption.

From "Assessment and Treatment of Destructive Behavior Maintained by Stereotypic Object Manipulation" by W. W. Fisher, S. E. Lindauer, C. J. Alterson, and R. H. Thompson, 1998, *Journal of Applied Behavior Analysis, 31,* p. 522.

3. Condition Change Lines. *Condition change lines* are vertical lines drawn upward from the horizontal axis to show points in time at which changes in the independent variable occurred. The condition change lines in Figure 6.2 coincide with the introduction or withdrawal of an intervention the researchers called blocking. Condition change lines can be drawn as solid or dashed lines. When relatively minor changes occur within an overall condition, dashed vertical lines should be used to distinguish minor changes from major changes in conditions, which are shown by solid lines (see Figure 6.18).

4. Condition Labels. *Condition labels,* in the form of single words or brief descriptive phrases, are printed along the top of the graph and parallel to the horizontal axis. These labels identify the experimental conditions (i.e., the presence, absence, or some value of the independent variable) that are in effect during each phase of the study.[4]

5. Data Points. Each *data point* on a graph represents two facts: (a) a quantifiable measure of the target behavior recorded during a given observation period and (b) the time and/or experimental conditions under which that particular measurement was conducted. Using two data points from Figure 6.2 as examples, we can see that during Session 5, the last session of the first baseline phase, property destruction and attempted property destruction responses occurred at a rate of approximately 2 responses per minute; and in Session 9, the fourth session of the first blocking phase, 0 instances of the target behavior were recorded.

6. Data Path. Connecting successive data points within a given condition with a straight line creates a data path. The **data path** represents the level and trend of behavior between successive data points, and it is a primary focus of attention in the interpretation and analysis of graphed data. Because behavior is rarely observed and recorded continuously in applied behavior analysis, the data path represents an estimate of the actual course taken by the behavior during the time elapsed between the two measures. The more measurements and resultant data points per unit of time (given an accurate observation and recording system), the more confidence one can place in the story told by the data path.

7. Figure Caption. The *figure caption* is a concise statement that, in combination with the axis and condition labels, provides the reader with sufficient information to identify the independent and dependent variables. The figure caption should explain any symbols or observed but unplanned events that may have affected the dependent variable (see Figure 6.6) and point out and clarify any potentially confusing features of the graph (see Figure 6.7).

Variations of the Simple Line Graph: Multiple Data Paths

The line graph is a remarkably versatile vehicle for displaying behavior change. Whereas Figure 6.2 is an example of the line graph in its simplest form (one data path showing a series of successive measures of behavior across time and experimental conditions) by the addition of multiple data paths, the line graph can display more complex behavior–environment relations. Graphs with multiple data paths are used frequently in applied behavior analysis to show (a) two or more dimensions of the same behavior, (b) two or more different behaviors, (c) the same behavior under different and alternating experimental conditions, (d) changes in target behavior relative to the changing values of an independent variable, and (e) the behavior of two or more participants.

Two or More Dimensions of the Same Behavior. Showing multiple dimensions of the dependent variable on the same graph enables visual analysis of the absolute and relative effects of the independent variable on those dimensions. Figure 6.3 shows the results of a study of the effects of training three members of a women's college basketball team proper foul shooting form (Kladopoulos & McComas, 2001). The data path created by connecting the open triangle data points shows changes in the percentage of foul shots executed with the proper form, whereas the data path connecting the solid data points reveals the percentage of foul shots made. Had the experimenters recorded and graphed only the players' foul shooting form, they would not have known whether any improvements in the target behavior on which training was focused (correct foul shooting form) coincided with improvements in the behavior by which the social significance of the study would ultimately be judged—foul shooting accuracy. By measuring and plotting both form and outcome on the same graph, the experimenters were able to analyze the effects of their treatment procedures on two critical dimensions of the dependent variable.

[4]The terms *condition* and *phase* are related but not synonymous. Properly used, *condition* indicates the environmental arrangements in effect at any given time; *phase* refers to a period of time within a study or behavior-change program. For example, the study shown in Figure 6.2 consisted of two conditions (baseline and blocking) and six phases.

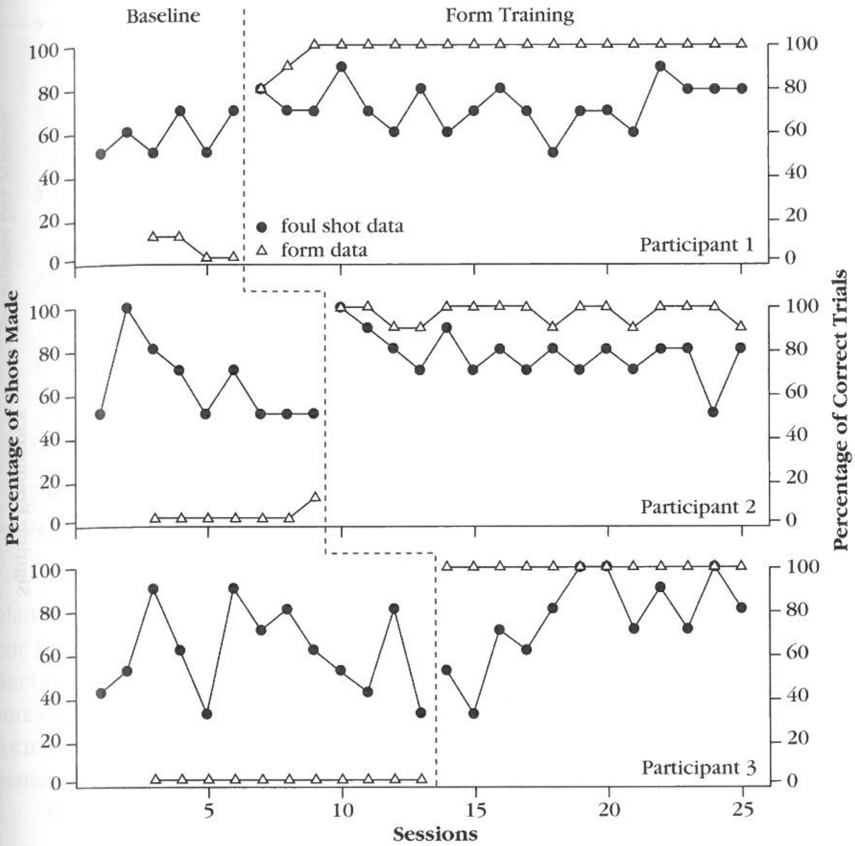


Figure 1. Percentage of shots made (filled circles) and percentage of shots taken with correct form (open triangles) across sessions for each participant.

Figure 6.3 Graph using multiple data paths to show the effects of the independent variable (Form Training) on two dimensions (accuracy and topography) of the target behavior.

From "The Effects of Form Training on Foul-Shooting Performance in Members of a Women's College Basketball Team" by C. N. Kladopoulos and J. J. McComas, 2001, *Journal of Applied Behavior Analysis, 34,* p. 331. Copyright 2001 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

Two or More Different Behaviors. Multiple data paths are also used to facilitate the simultaneous comparison of the effects of experimental manipulations on two or more different behaviors. Determining the covariation of two behaviors as a function of changes in the independent variable is accomplished more easily if both can be displayed on the same set of axes. Figure 6.4 shows the percentage of intervals in which a boy with autism exhibited stereotypy (e.g., repetitive body movements, rocking) across three conditions and the number of times that he raised his hand for attention (in the attention condition), signed for a break (in the demand condition), and signed for access to preferred tangible stimuli (in the no-attention condition) in a study investigating a strategy called functional communication training (Kennedy, Meyer, Knowles, & Shukla, 2000).[5] By recording and graphing both stereotypic responding and appropriate behavior, the investigators were able to determine whether increases in alternative communication responses (raising his hand and signing) were accompanied by reductions in stereotypy. Note that a second vertical axis is used on Figure 6.4 to show the proper dimensional units and scaling for signing frequency. Because of the differences in scale, readers of dual-vertical axis graphs must view them with care, particularly when assessing the magnitude of behavior change.

Measures of the Same Behavior under Different Conditions. Multiple data paths are also used to represent measures of the same behavior taken under different experimental conditions that alternate throughout an experimental phase. Figure 6.5 shows the number of self-injurious response per minute by a 6-year-old girl with developmental disabilities under four different conditions (Moore, Mueller, Dubard, Roberts, & Sterling-Turner, 2002). Graphing an individual's behavior under multiple conditions on the same set of axes allows direct visual comparisons of differences in absolute levels of responding at any given time as well as relative changes in performance over time.

Changing Values of an Independent Variable. Multiple data path graphs are also used to show changes in the target behavior (shown on one data path) relative to changing values of the independent variable (represented by a second data path). In each of the two graphs

[5]Functional communication training is described in Chapter 23.

Figure 6.4 Graph with multiple data paths showing two different behaviors by one participant during baseline and training across three different conditions. Note the different dimensions and scaling of the dual vertical axes.

From "Analyzing the Multiple Functions of Stereotypical Behavior for Students with Autism: Implications for Assessment and Treatment" by C. H. Kennedy, K. A. Meyer, T. Knowles, and S. Shukla, 2000, *Journal of Applied Behavior Analysis, 33,* p. 565. Copyright 2000 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

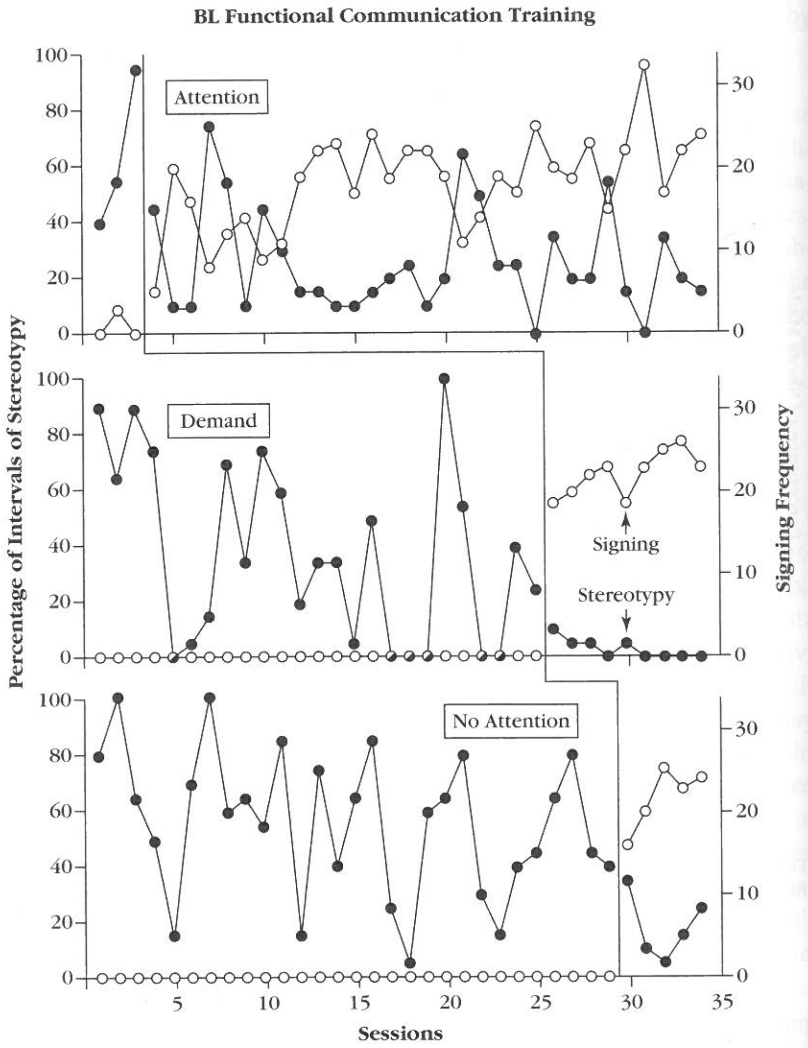


Figure 2. Occurrence of stereotypy for James across attention, demand, and no-attention conditions. Data are arrayed as the percentage of intervals of stereotypy on the left *y* axis and number of signs per sessions on the right *y* axis.

in Figure 6.6 one data path shows the duration of problem behavior (plotted against the left-hand *y* axis scaled in seconds) relative to changes in noise level, which are depicted by the second data path (plotted against the right-hand *y* axis scaled in decibels) (McCord, Iwata, Galensky, Ellingson, & Thomson, 2001).

The Same Behavior of Two or More Participants. Multiple data paths are sometimes used to show the behavior of two or more participants on the same graph.

Depending on the levels and variability of the data encompassed by each data path, a maximum of four different data paths can be displayed effectively on one set of axes. However, there is no rule; Didden, Prinsen, and Sigafoos displayed five data paths in a single display (2000, p. 319). If too many data paths are displayed on the same graph, the benefits of making additional comparisons may be outweighed by the distraction of too much visual "noise." When more than four data paths must be included on the same graph, other methods of display can be incorporated.[6] For example, Gutowski and Stromer (2003) effectively used striped and shaded bars in combination with conventional data paths to display the number of names spoken and the percentage of correct matching-to-sample responses by individuals with mental retardation (see Figure 6.7).

Bar Graphs

The **bar graph,** or histogram, is a simple and versatile format for graphically summarizing behavioral data. Like the line graph, the bar graph is based on the Cartesian

[6]A superb example of combining visual display techniques is Charles Minard's use of space-time-story graphics to illustrate the interrelations of six variables during Napoleon's ill-fated Russian campaign of 1812–1813 (see Tufte, 1983, p. 41). Tufte called Minard's graph perhaps "the best statistical graphic ever drawn" (p. 40).

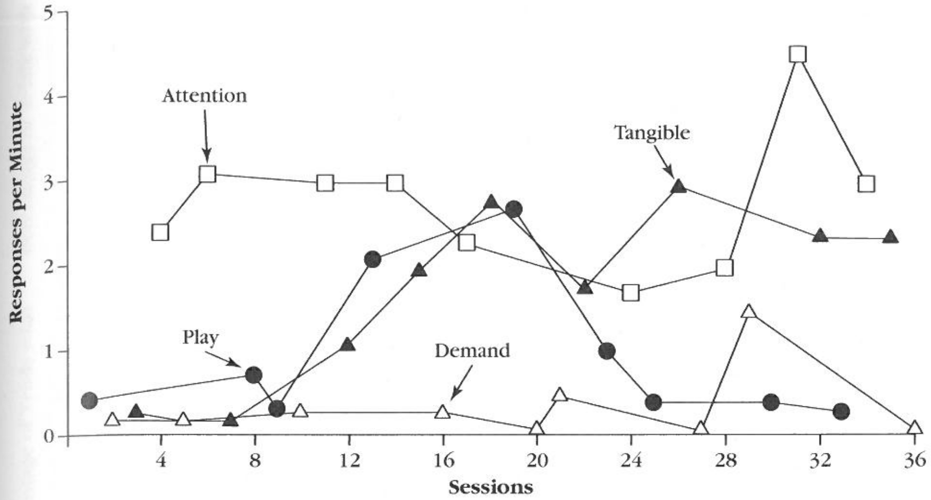


Figure 1. Rate of self-injurious behavior during the initial functional analysis.

Figure 6.5 Graph with multiple data paths showing the same behavior measured under four different conditions.

From "The Influence of Therapist Attention on Self-Injury during a Tangible Condition" by J. W. Moore, M. M. Mueller, M. Dubard, D. S. Roberts, and H. E. Sterling-Turner, 2002, *Journal of Applied Behavior Analysis, 35,* p. 285. Copyright 2002 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

plane and shares most of the line graph's features with one primary difference: The bar graph does not have distinct data points representing successive response measures through time. Bar graphs can take a wide variety of forms to allow quick and easy comparisons of performance across participants and/or conditions.

Bar graphs serve two major functions in applied behavior analysis. First, bar graphs are used for displaying and comparing discrete sets of data that are not related to one another by a common underlying dimension by which the horizontal axis can be scaled. For example, Gottschalk, Libby, and Graff (2000), in a study analyzing

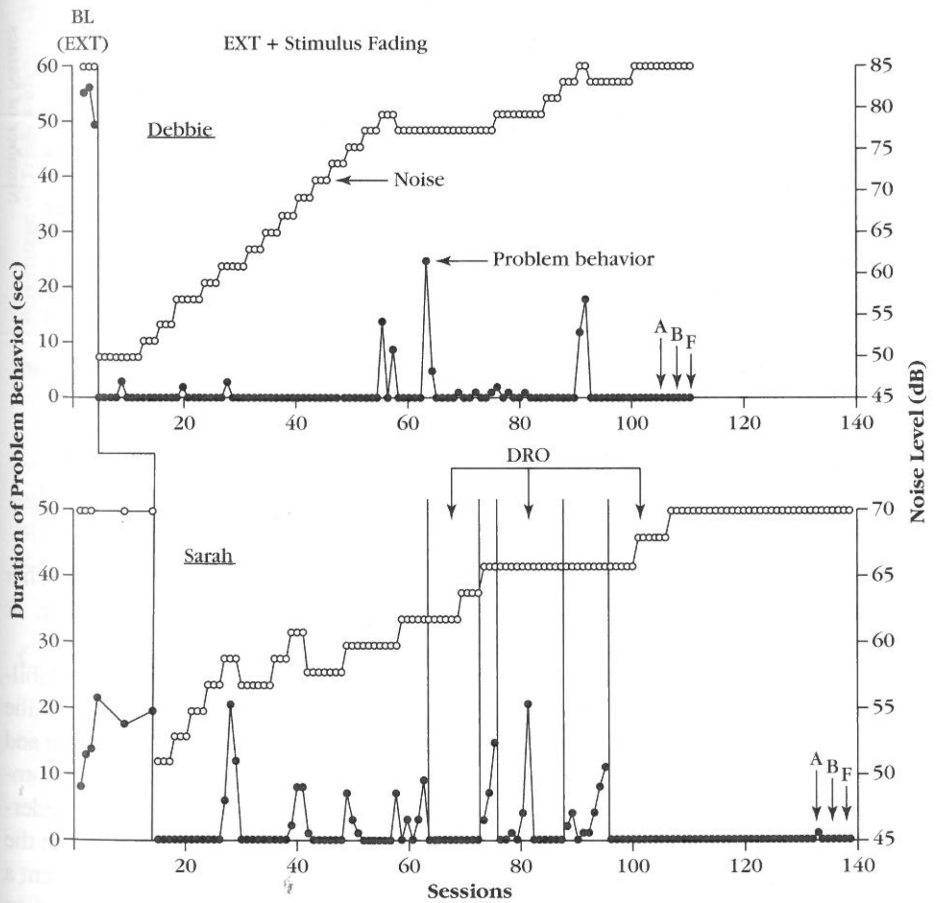


Figure 4. Results of Debbie's and Sarah's treatment evaluation. Sessions marked A and B near the end of treatment indicate two generalization probes in the natural environment; F indicates a follow-up probe.

Figure 6.6 Graph using two data paths to show the duration of problem behavior (dependent variable) by two adults with severe or profound mental retardation as noise level was increased gradually (independent variable).

From "Functional Analysis and Treatment of Problem Behavior Evoked by Noise" by B. E. McCord, B. A. Iwata, T. L. Galensky, S. A. Ellingson, and R. J. Thomson, 2001, *Journal of Applied Behavior Analysis, 34,* p. 457. Copyright 2001 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

Figure 6.7 Graph using a combination of bars and data points to display changes in two response classes to two types of matching stimuli under different prompting conditions.

From "Delayed Matching to Two-Picture Samples by Individuals With and Without Disabilities: An Analysis of the Role of Naming" by S. J. Gutowski and Robert Stromer, 2003, *Journal of Applied Behavior Analysis, 36,* p. 498. Copyright 2003 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted by permission.

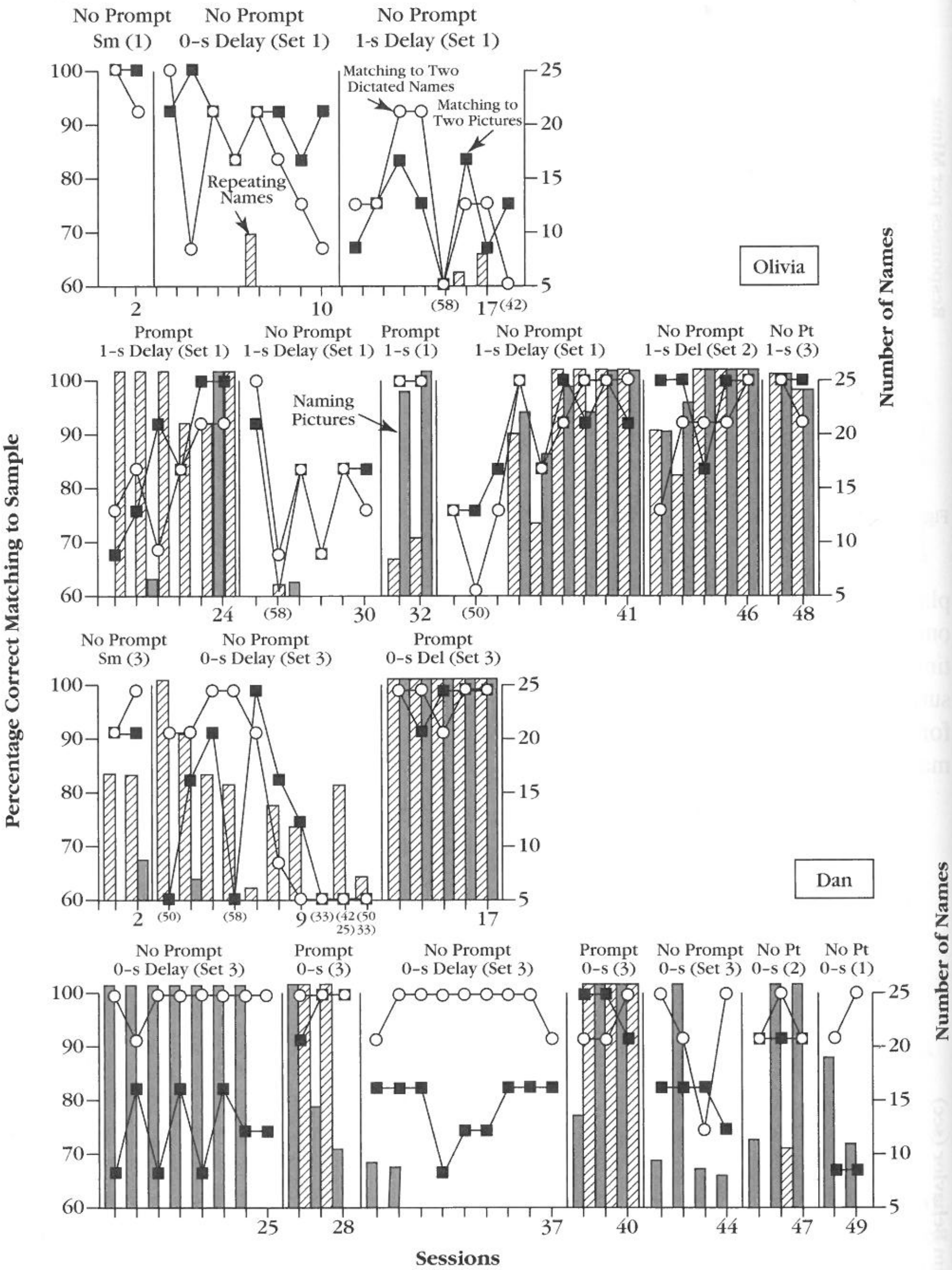


Figure 4. Results for Olivia and Dan across simultaneous, delay, prompt, and no-prompt conditions: open circles and solid squares reflect percentages of correct matching. Striped bars and shaded bars reflect the number of names spoken on trials with two-name and two-picture samples, respectively. Bars with extended tic marks on the abscissa indicate that the number of names exceeded 25.

the effects of establishing operations on preference assessments, used bar graphs to show the percentage of trials in which four children reached toward and picked up different items (see Figure 6.8).

Another common use of bar graphs is to give a visual summary of the performance of a participant or group of participants during the different conditions of an experiment. For example, Figure 6.9 shows the mean percentage of spelling worksheet items completed and the mean percentage of completed items that were done correctly by four students during baseline and combined generalization programming and maintenance conditions that followed training each child how to recruit teacher attention while they were working (Craft, Alber, & Heward, 1998).

Bar graphs sacrifice the presentation of the variability and trends in behavior (which are apparent in a line graph) in exchange for the efficiency of summarizing and comparing large amounts of data in a simple, easy-to-interpret format. They should be viewed with the understanding that they may mask important variability in the data. Although bar graphs are typically used to present a measure of central tendency, such as the mean or median score for each condition, the range of measures repre-

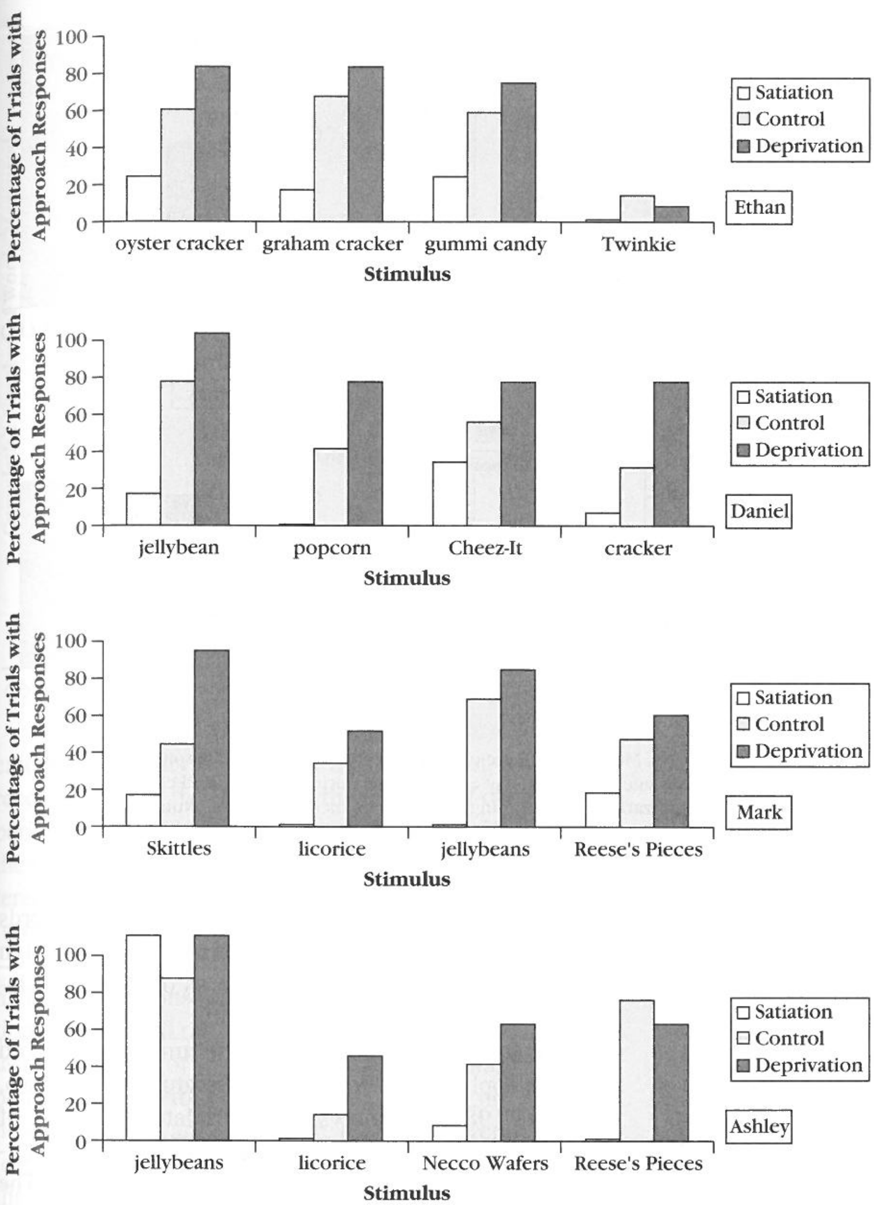


Figure 1. Percentage of approach responses across conditions for Ethan, Daniel, Mark, and Ashley.

Figure 6.8 Bar graph used to summarize and display results of measurements taken under discrete conditions lacking an underlying dimension by which the horizontal axis could be scaled (e.g., time, duration of stimulus presentations).

From "The Effects of Establishing Operations on Preference Assessment Outcomes" by J. M. Gottschalk, M. E. Libby, and R. B Graff, 2000, *Journal of Applied Behavior Analysis, 33,* p. 87. Copyright 2000 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted by permission.

sented by the mean can also be incorporated into the display (e.g., see Figure 5 in Lerman, Kelley, Vorndran, Kuhn, & LaRue, 2002).

Cumulative Records

The **cumulative record** (or graph) was developed by Skinner as the primary means of data collection in the experimental analysis of behavior. A device called the **cumulative recorder** enables a subject to actually draw its own graph (see Figure 6.10). In a book cataloging 6 years of experimental research on schedules of reinforcement, Ferster and Skinner (1957) described cumulative records in the following manner:

> A graph showing the number of responses on the ordinate against time on the abscissa has proved to be the most convenient representation of the behavior observed in this research. Fortunately, such a "cumulative" record may be made directly at the time of the experiment. The record is raw data, but it also permits a direct inspection of rate and changes in rate not possible when the behavior is observed directly. . . . Each time the bird responds, the pen moves one step across the paper. At the same time, the paper feeds continuously. If the bird does not respond at all, a horizontal line is drawn in the direction of the paper feed. The faster the bird pecks, the steeper the line. (p. 23)

When cumulative records are plotted by hand or created with a computer graphing program, which is most

Figure 6.9 Bar graph comparing mean levels for two dimensions of participants' performance between experimental conditions.

From "Teaching Elementary Students with Developmental Disabilities to Recruit Teacher Attention in a General Education Classroom: Effects on Teacher Praise and Academic Productivity" by M. A. Craft, S. R. Alber, and W. L. Heward, 1998, *Journal of Applied Behavior Analysis, 31,* p. 410. Copyright 1998 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted by permission.

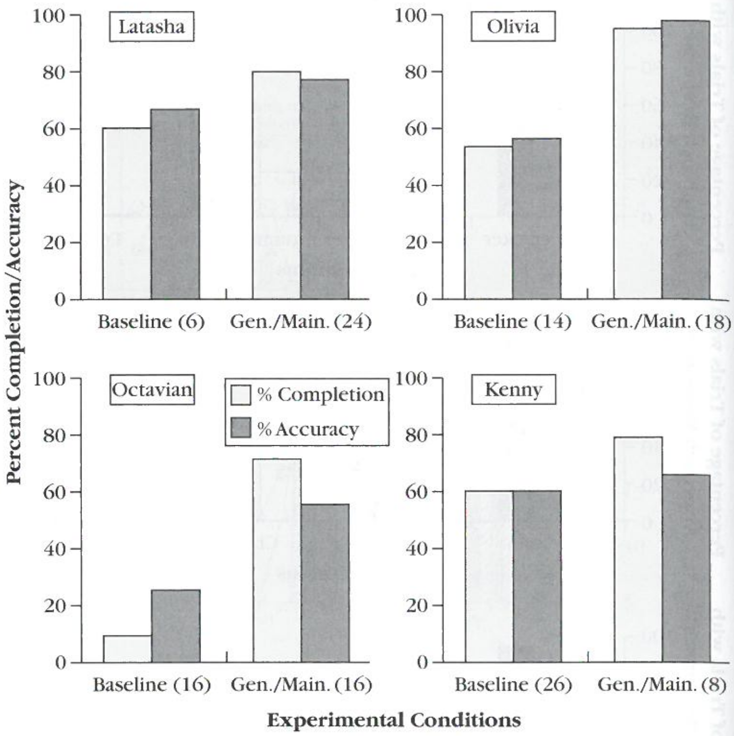


Figure 4. Mean percentage of spelling worksheet items completed and mean percentage of accuracy by each student during baseline and combined generalization programming and maintenance conditions. Numbers in parentheses show total number of sessions per condition.

often the case in applied behavior analysis, the number of responses recorded during each observation period is added (thus the term *cumulative*) to the total number of responses recorded during all previous observation periods. In a cumulative record the *y* axis value of any data point represents the total number of responses recorded since the beginning of data collection. The exception occurs when the total number of responses has exceeded the upper limit of the *y* axis scale, in which case the data path on a cumulative curve resets to the 0 value of the *y* axis and begins its ascent again. Cumulative records are almost always used with frequency data, although other dimensions of behavior, such as duration and latency, can be displayed cumulatively.

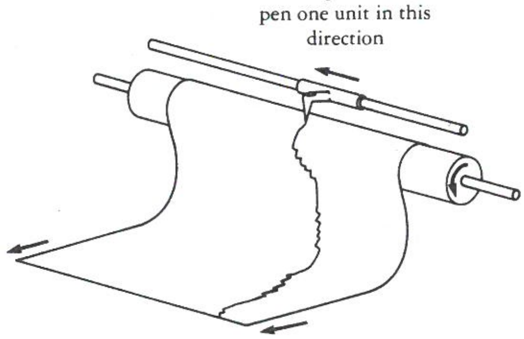


Figure 6.10 Diagram of a cumulative recorder.

From *Schedules of Reinforcement*, pp. 24–25, by C. B. Ferster and B. F. Skinner, 1957, Upper Saddle River, NJ: Prentice Hall. Copyright 1957 by Prentice Hall. Used by permission.

Figure 6.11 is an example of a cumulative record from the applied behavior analysis literature (Neef, Iwata, & Page, 1980). It shows the cumulative number of spelling words mastered by a person with mental retardation during baseline and two training conditions. The graph shows that the individual mastered a total of 1 word during the 12 sessions of baseline (social praise for correct spelling responses and rewriting incorrectly spelled words three times), a total of 22 words under the interspersal condition (baseline procedures plus the presentation of a previously learned word after each unknown word), and a total of 11 words under the high-density reinforcement condition (baseline procedures plus social praise given after each trial for task-related behaviors such as paying attention and writing neatly).

In addition to the total number of responses recorded at any given point in time, cumulative records show the overall and local response rates. Rate is the number of responses emitted per unit of time, usually reported as responses per minute in applied behavior analysis. An **overall response rate** is the average rate of response over a given time period, such as during a specific session, phase, or condition of an experiment. Overall rates are

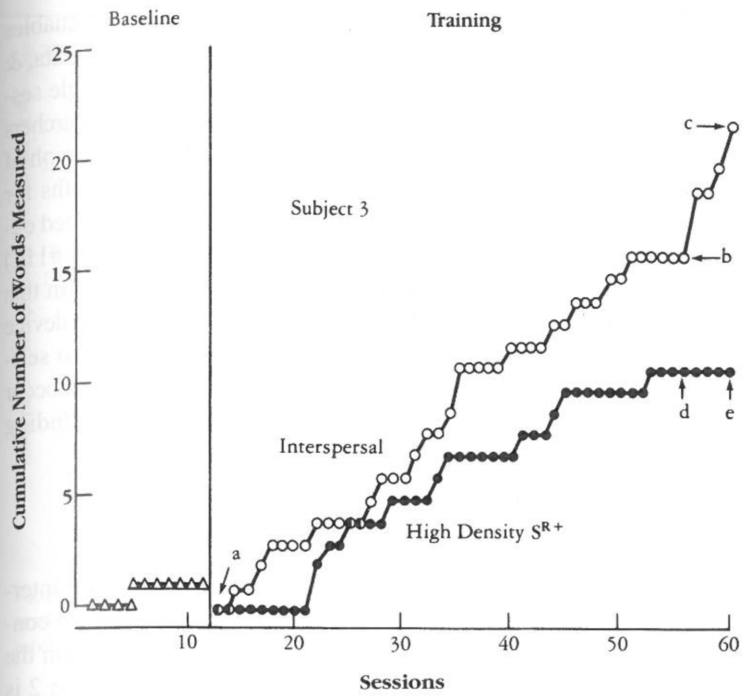


Figure 6.11 Cumulative graph of number of spelling words learned by a man with mental retardation during baseline, interspersal training, and high-density reinforcement training. Points a–e have been added to illustrate the differences between overall and local response rates.

From "The Effects of Interspersal Training Versus High Density Reinforcement on Spelling Acquisition and Retention" by N. A. Neef, B. A. Iwata, and T. J. Page, 1980, *Journal of Applied Behavior Analysis, 13,* p. 156. Copyright 1980 by the Society for the Experimental Analysis of Behavior, Inc. Adapted by permission.

calculated by dividing the total number of responses recorded during the period by the number of observation periods indicated on the horizontal axis. In Figure 6.11 the overall response rates are 0.46 and 0.23 words mastered per session for the interspersal and high-density reinforcement conditions, respectively.[7]

On a cumulative record, the steeper the slope, the higher the response rate. To produce a visual representation of an overall rate on a cumulative graph, the first and last data points of a given series of observations should be connected with a straight line. A straight line connecting Points a and c in Figure 6.11 would represent the learner's overall rate of mastering spelling words during the interspersal condition. A straight line connecting Points a and e represents the overall rate during the high-density reinforcement condition. Relative rates of response can be determined by visually comparing one slope to another; the steeper the slope, the higher the rate of response. A visual comparison of Slopes a–c and a–e shows that the interspersal condition produced the higher overall response rate.

Response rates often fluctuate within a given period. The term **local response rate** refers to the rate of response during periods of time smaller than that for which an overall rate has been given. Over the last four sessions of the study shown in Figure 6.11, the learner exhibited a local rate of responding during interspersal training (Slope b–c) that was considerably higher than his overall rate for that condition. At the same time his performance during the final four sessions of the high-density reinforcement condition (Slope d–e) shows a lower local response rate than his overall rate for that condition.

A legend giving the slopes of some representative rates can aid considerably in the determination and comparison of relative response rates both within and across cumulative curves plotted on the same set of axes (e.g., see Kennedy & Souza, 1995, Figure 2). However, very high rates of responding are difficult to compare visually with one another on cumulative records.

> Although the rate of responding is directly proportional to the slope of the curve, at slopes above 80 degrees small differences in angle represent very large differences in rate; and although these can be measured accurately, they cannot be evaluated easily by [visual] inspection. (Ferster & Skinner, 1957, pp. 24–25)

Even though cumulative records derived from continuous recording are the most directly descriptive displays of behavioral data available, two other features of behavior, in addition to the comparison of very high rates, can be difficult to determine on some cumulative graphs. One, although the total number of responses since data collection began can be easily seen on a cumulative graph, the number of responses recorded for any given session can be hard to ascertain, given the number of data points and the scaling of the vertical axis. Two, gradual changes in slope from one rate to another can be hard to detect on cumulative graphs.

[7]Technically, Figure 6.11 does not represent true rates of response because the number of words spelled correctly was measured and not the rate, or speed, at which they were spelled. However, the slope of each data path represents the different "rates" of mastering the spelling words in each session within the context of a total of 10 new words presented per session.

Four situations in which a cumulative graph may be preferable to a noncumulative line graph are as follows. First, cumulative records are desirable when the total number of responses made over time is important or when progress toward a specific goal can be measured in cumulative units of behavior. The number of new words learned, dollars saved, or miles trained for an upcoming marathon are examples. One look at the most recent data point on the graph reveals the total amount of behavior up to that point in time.

Second, a cumulative graph might also be more effective than noncumulative graphs when the graph is used as a source of feedback for the participant. This is because both total progress and relative rate of performance are easily detected by visual inspection (Weber, 2002).

Third, a cumulative record should be used when the target behavior is one that can occur or not occur only once per observation session. In these instances the effects of any intervention are easier to detect on a cumulative graph than on a noncumulative graph. Figure 6.12 shows the same data plotted on a noncumulative graph and a cumulative graph. The cumulative graph clearly shows a relation between behavior and intervention, whereas the noncumulative graph gives the visual impression of greater variability in the data than really exists.

Fourth, cumulative records can "reveal the intricate relations between behavior and environmental variables" (Johnston & Pennypacker, 1993a, p. 317) Figure 6.13 is an excellent example of how a cumulative graph enables a detailed analysis of behavior change (Hanley, Iwata, & Thompson, 2001). By plotting the data from single sessions cumulatively by 10-second intervals, the researchers revealed patterns of responding not shown by a graph of session-by-session data. Comparing the data paths for the three sessions for which the results were graphed cumulatively (Mult #106, Mixed #107, and Mixed #112) revealed two undesirable patterns of responding (in this case, pushing a switch that operated a voice output device that said "talk to me, please" as an alternative to self-injurious behavior and aggression) that are likely to occur during mixed schedules, and the benefits of including schedule-correlated stimuli (Mult #106).

Semilogarithmic Charts

All of the graphs discussed so far have been equal-interval graphs on which the distance between any two consecutive points on each axis is always the same. On the x axis the distance between Session 1 and Session 2 is equal to the distance between Session 11 and Session 12; on the y axis, the distance between 10 and 20 responses per minute is equal to the distance between 35 and 45 responses per minute. On an equal-interval graph equal absolute changes in behavior, whether an increase or decrease in performance, are expressed by equal distances on the y axis.

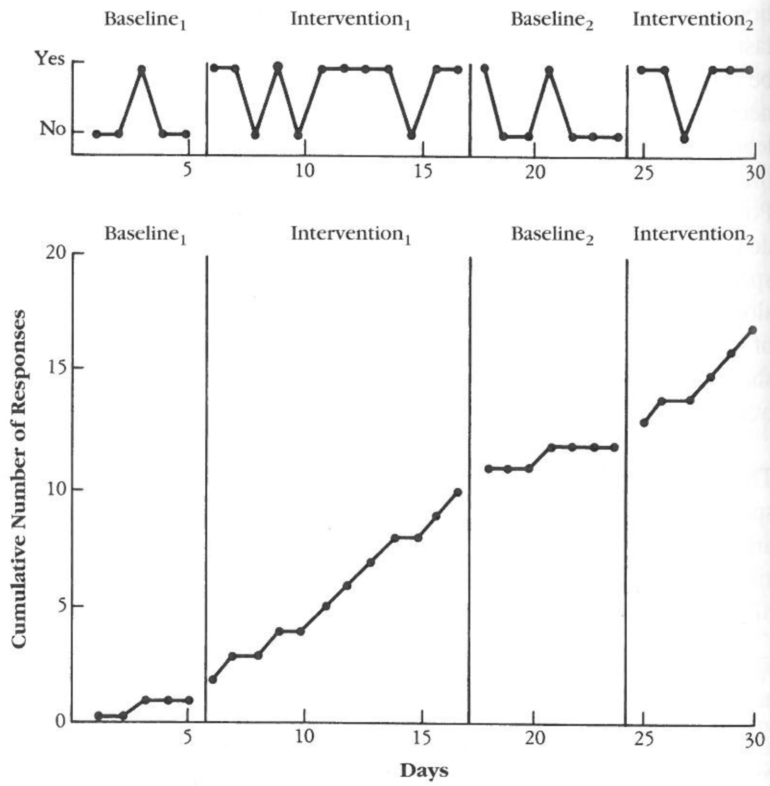


Figure 6.12 Same set of hypothetical data plotted on noncumulative and cumulative graphs. Cumulative graphs more clearly reveal patterns of and changes in responding for behaviors that can occur only once during each period of measurement.

From *Working with Parents of Handicapped Children,* p. 100, by W. L. Heward, J. C. Dardig, and A. Rossett, 1979, Columbus, OH: Charles E. Merrill. Copyright 1979 by Charles E. Merrill. Used by permission.

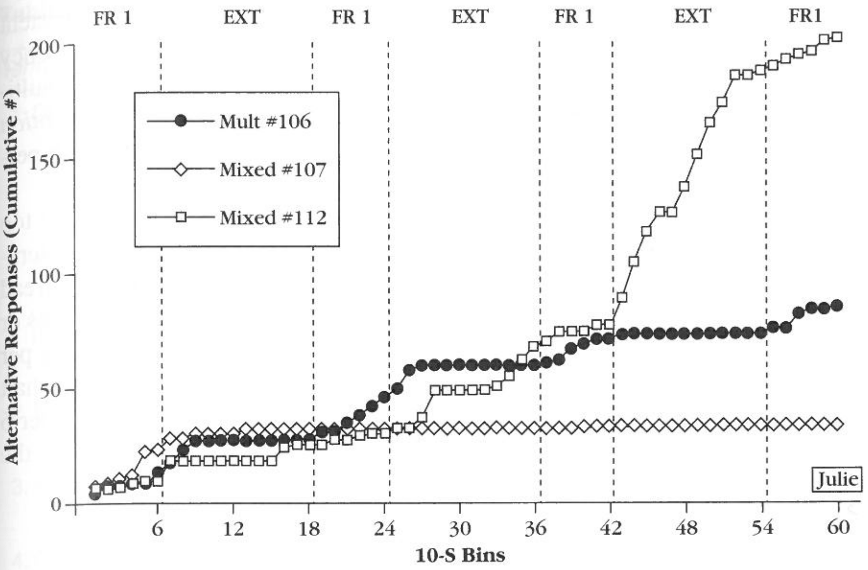


Figure 4. Cumulative number of alternative responses across schedule components for three sessions from Julie's assessment of schedule-correlated stimuli. Open symbols represent two mixed-schedule sessions; filled symbols represent a single multiple-schedule session.

Figure 6.13 Cumulative record used to make a detailed analysis and comparison of behavior across components of multiple- and mixed-reinforcement schedules within specific sessions of a study.

From "Reinforcement Schedule Thinning Following Treatment with Functional Communication Training" by G. P. Hanley, B. A. Iwata, and R. H. Thompson, 2001, *Journal of Applied Behavior Analysis, 34,* p. 33. Copyright 2001 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

Another way of looking at behavior change is to examine proportional or relative change. Logarithmic scales are well suited to display and communicate proportional change. On a logarithmic scale equal relative changes in the variable being measured are represented by equal distances. Because behavior is measured and charted over time, which progresses in equal intervals, the *x* axis is marked off in equal intervals and only the *y* axis is scaled logarithmically. Hence, the term **semilogarithmic chart** refers to graphs in which only one axis is scaled proportionally.

On semilog charts all behavior changes of equal proportion are shown by equal vertical distances on the vertical axis, regardless of the absolute values of those changes. For example, a doubling of response rate from 4 to 8 per minute would appear on a semilogarithmic chart as the same amount of change as a doubling of 50 to 100 responses per minute. Likewise, a decrease in responding from 75 to 50 responses per minute (a decrease of one third) would occupy the same distance on the vertical axis as a change from 12 to 8 responses per minute (a decrease of one third).

Figure 6.14 shows the same data graphed on an equal-interval chart (sometimes called arithmetic or add-subtract charts) and on a semilogarithmic chart (sometimes called ratio or multiply-divide charts). The behavior change that appears as an exponential curve on the arithmetic chart is a straight line when plotted on the semilog chart. The vertical axis in the semilog chart in Figure 6.14 is scaled by log-base-2 or X2 cycles, which means that each cycle going up on the *y* axis represents a times-2 increase (i.e., a doubling) of the cycle below it.

Standard Celeration Charts

In the 1960s, Ogden Lindsley developed the **Standard Celeration Chart** to provide a standardized means of charting and analyzing how frequency of behavior

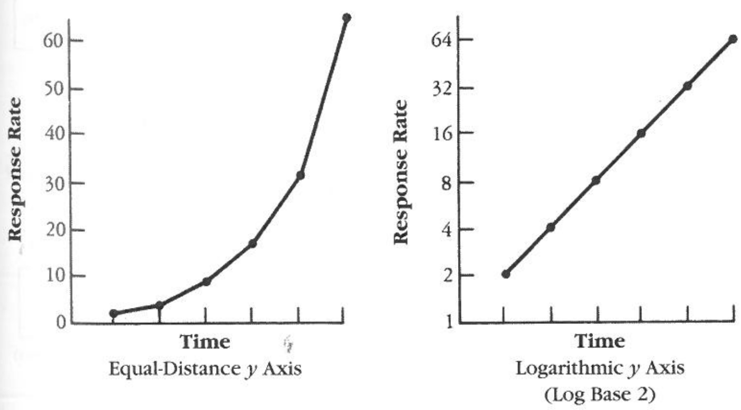


Figure 6.14 Same set of data plotted on equal-interval arithmetic scale (left) and on equal-proportion ratio scale (right).

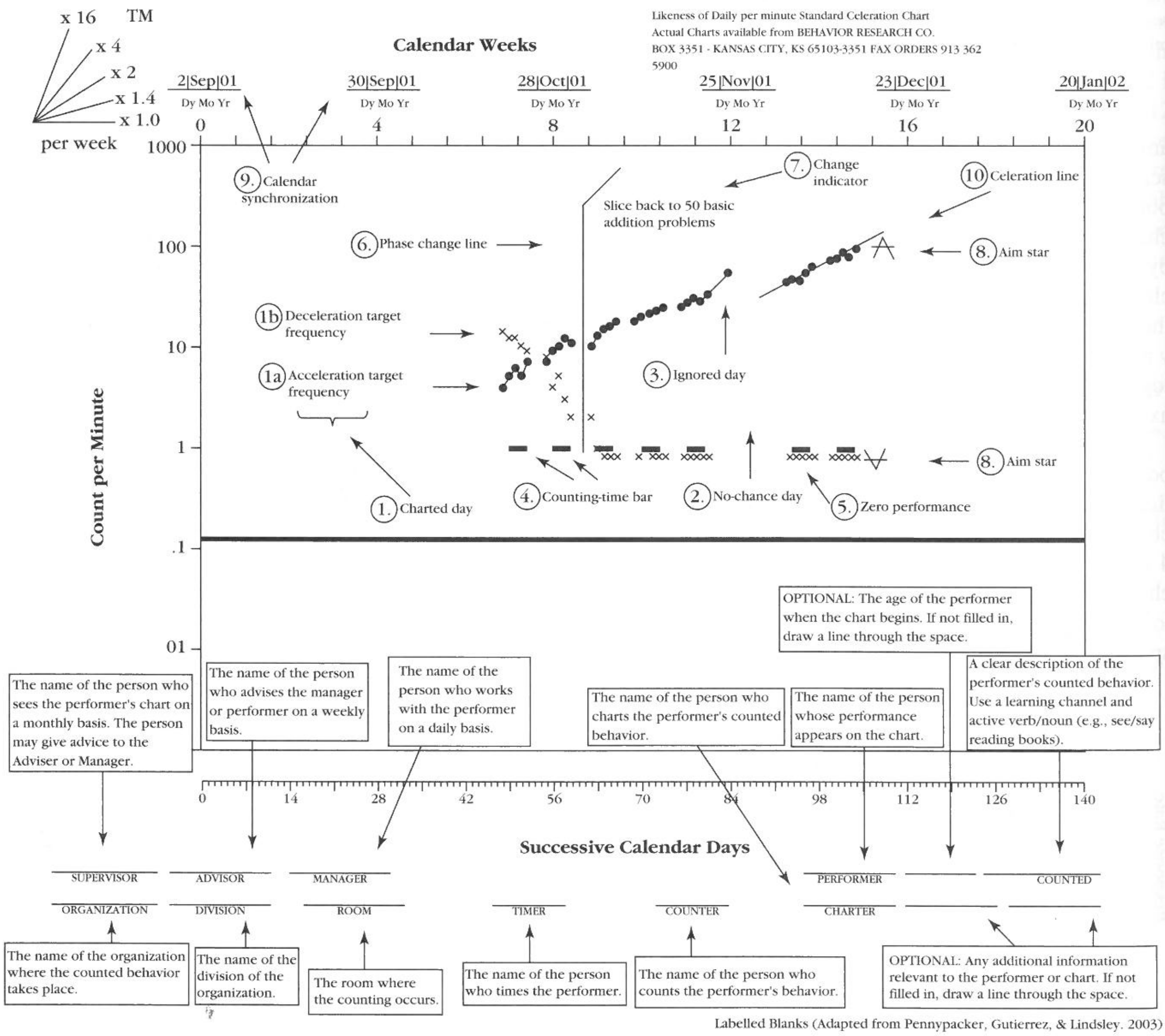
changes over time (Lindsley, 1971; Pennypacker, Gutierrez & Lindsley, 2003). The Standard Celeration Chart is a semilogarithmic chart with six X10 cycles on the vertical axis that can accommodate response rates as low as 1 per 24 hours (0.000695 per minute) or as high as 1,000 per minute.

There are four standard charts, differentiated from one another by the scaling on the horizontal axis: a daily chart with 140 calendar days, a weekly chart, a monthly chart, and a yearly chart. The daily chart shown in Figure 6.15 is used most often. Table 6.1 describes major parts of the Standard Celeration Chart and basic charting conventions.

The size of the chart and the consistent scaling of the *y* axis and *x* axis do not make the Standard Celeration Chart *standard,* as is commonly believed. What makes the Standard Celeration Chart standard is its consistent display of *celeration,* a linear measure of frequency change across time, a factor by which frequency multiplies or divides per unit of time. The terms *acceleration* and *deceleration* are used to describe accelerating performances or decelerating performances.

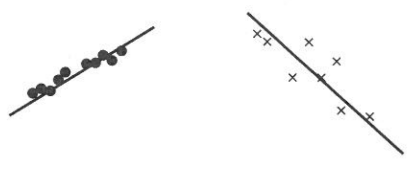
A line drawn from the bottom left corner to the top right corner has a slope of 34° on all Standard Celeration Charts. This slope has a celeration value of X2 (read as "times-2"; celerations are expressed with multiples or divisors). A X2 celeration is a doubling in frequency per celeration period. The celeration period for the daily chart is per week; it is per month for the weekly chart, per 6 months for the monthly chart, and per 5 years for the yearly chart.

Figure 6.15 Standard Celeration Chart showing basic charting conventions. See Table 6.1 for explanation.



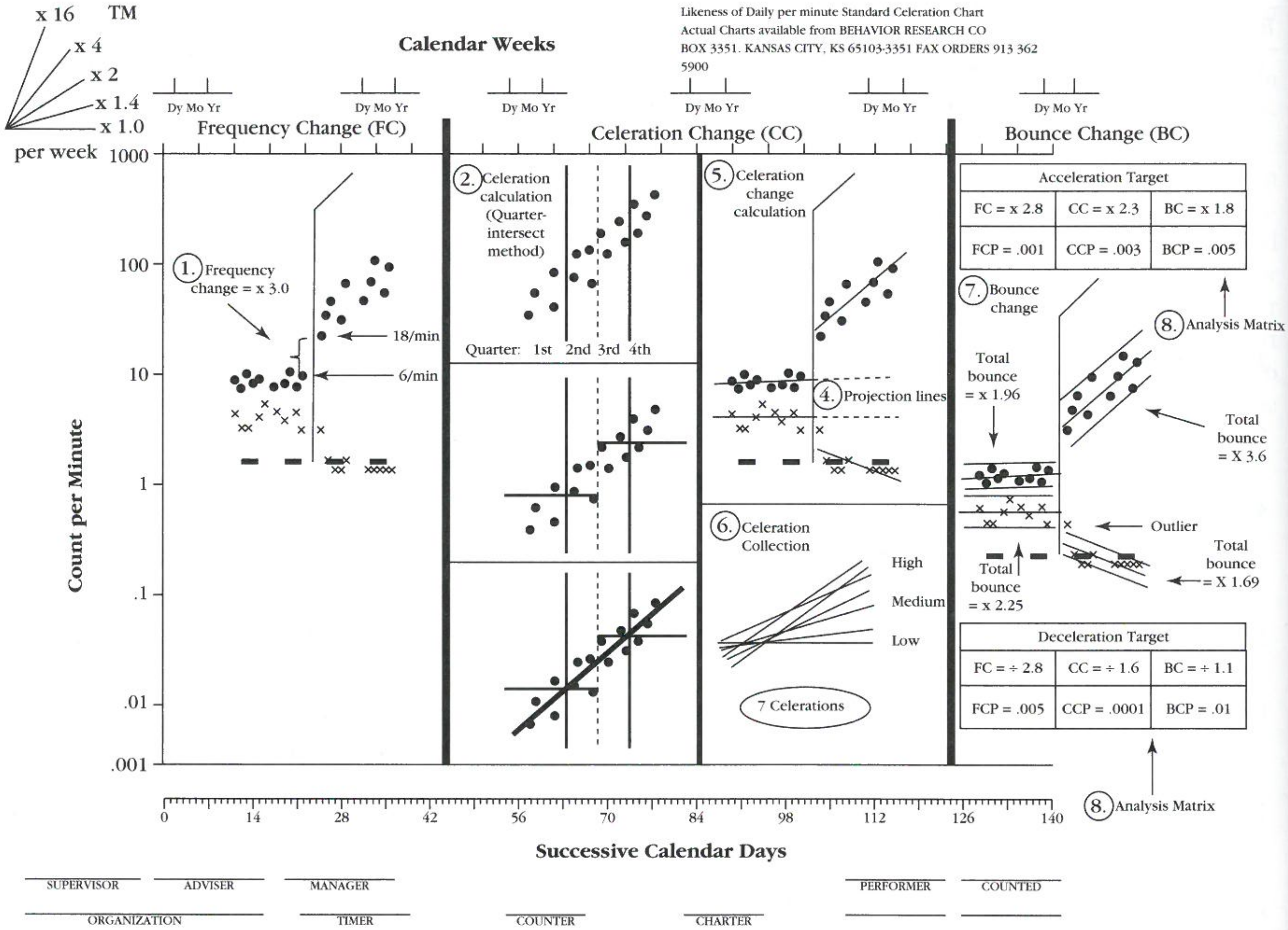
From the *Journal of Precision Teaching and Celeration, 19*(1), p. 51. Copyright 2003 by The Standard Celeration Society. Used by permission.

Table 6.1 Basic Charting Conventions for the Daily Standard Celeration Chart (See also Figure 6.15)

Term	*Definition*	*Convention*
1. Charted day	A day on which the behavior is recorded and charted.	1. Chart the behavior frequency on the chart on the appropriate day line. 2. Connect charted days except across *phase change lines, no chance days,* and *ignored days.*
a) Acceleration target frequency	Responses of the performer intended to accelerate.	Chart a dot (•) on the appropriate day line.
b) Deceleration target frequency	Responses of the performer intended to decelerate.	Chart an (x) on the appropriate day line.
2. No chance day	A day on which the behavior had *no chance* to occur.	Skip day on daily chart.
3. Ignored day	A day on which the behavior could have occurred but no one recorded it.	Skip day on daily chart. (Connect data across ignored days.)
4. Counting-time bar (aka record floor)	Designates on the chart the performer's lowest possible performance (other than zero) in a counting time. Always designated as "once per counting time."	Draw solid horizontal line from the Tuesday to Thursday day lines on the chart at the "counting-time bar."
5. Zero performance	No performance recorded during the recording period.	Chart on the line directly below the "counting-time bar."
6. Phase change line	A line drawn in the space between the last charted day of one intervention phase and the first charted day of a new intervention phase.	Draw a vertical line between the intervention phases. Draw the line from the top of the data to the "counting-time bar."
7. Change indicator	Words, symbols, or phrases written on the chart in the appropriate phase to indicate changes during that phase.	Write word, symbol, and/or phrase. An arrow (→) may be used to indicate the continuance of a change into a new phase.
8. Aim star	A symbol used to represent (a) the desired frequency, and (b) the desired date to achieve the frequency.	Place the point of the caret . . . ^ for acceleration data v for deceleration data . . . on the desired aim date. Place the horizontal bar on the desired frequency. The caret and horizontal line will create a "star."
9. Calendar synchronize	A standard time for starting all charts.	It requires three charts to cover a full year. The Sunday before Labor Day begins the first week of the first chart. The twenty-first week after Labor Day begins the second chart. The forty-first week after Labor Day begins the third chart.
10. Celeration line	A straight line drawn through 7–9 or more charted days. This line indicates the amount of improvement that has taken place in a given period of time. A new line is drawn for each phase for both acceleration and deceleration targets. (Note: For nonresearch projects it is acceptable to draw freehand celeration lines.)	 Acceleration target Deceleration target

From the *Journal of Precision Teaching and Celeration, 19*(1), pp. 49–50.

Figure 6.16 Standard Celeration Chart showing advanced charting conventions. See Table 6.2 for explanation.



From the *Journal of Precision Teaching and Celeration, 19*(1), p. 54. Copyright 2002 by The Standard Celeration Society. Used by permission.

An instructional decision-making system, called *precision teaching,* has been developed for use with the Standard Celeration Chart.[8] Precision teaching is predicated on the position that (a) learning is best measured as a change in response rate, (b) learning most often occurs through proportional changes in behavior, and (c) past changes in performance can project future learning.

Precision teaching focuses on celeration, not on the specific frequency of correct and incorrect responses as many believe. That frequency is not an emphasis on the Chart is clear because the Chart uses estimations for most frequency values. A practitioner or researcher might say, "I don't use the chart because I can't tell by looking at the chart if the student emitted 24, 25, 26, or 27 responses." However, the purpose of the Chart makes such a fine discrimination irrelevant because celeration, not specific frequency, is the issue. A frequency of 24 or 27 will not change the line of progress—the celeration course.

Advanced charting conventions used by precision teachers are illustrated in Figure 6.16 and described in Table 6.2. Detailed explanations of the Standard Celeration Chart and its uses can be found in Cooper, Kubina, and Malanga (1998); Graf and Lindsley (2002); and Pennypacker, Gutierrez, and Lindsley (2003).

Scatterplots

A **scatterplot** is a graphic display that shows the relative distribution of individual measures in a data set with respect to the variables depicted by the x and y axes. Data points on a scatterplot are unconnected. Scatterplots show how much changes in the value of the variable depicted by one axis correlate with changes in the value of the variable represented by the other axis. Patterns of data

[8]Detailed descriptions and examples of precision teaching are provided by the *Journal of Precision Teaching and Celeration;* the Standard Celeration Society's Web site (http://celeration.org/); Binder (1996); Kubina and Cooper (2001); Lindsley (1990, 1992, 1996); Potts, Eshleman, and Cooper (1993); West, Young, and Spooner (1990); and White and Haring (1980).

Table 6.2 Advanced Charting Conventions for the Daily Standard Celeration Chart (See also Figure 6.16)

Term	*Definition*	*Convention*
Frequency:		
1. Frequency change (FC) (aka frequency jump up or jump down)	The multiply "×" or divide "÷" value that compares the final frequency of one phase to the beginning frequency in the next phase. Compute this by comparing (1) the frequency where the celeration line crosses the *last* day of one phase to (2) the frequency where the celeration line crosses the *first* day of the next phase (e.g., a frequency jump from 6/minute to 18/minute. FC = × 3.0).	Place an "FC =" in the upper left cell of the analysis matrix. Indicate the value with a "×" or "÷" sign (e.g., FC = × 3.0).
Celeration:		
2. Celeration calculation (quarter-intersect method)	The process for *graphically* determining a celeration line (aka "the line of best fit"). (1) Divide the frequencies for each phase into four equal quarters (include ignored and no chance days), (2) locate the median frequency for each half, and (3) draw a celeration line connecting the quarter intersect points.	See advanced charting conventions sample chart.
3. Celeration finder	A piece of mylar with standard celeration lines that can be used to compute celeration line values.	Buy commercially or copy and cut out part of the vertical axis on the Standard Celeration Chart.
4. Projection line	A dashed line extending to the future from the celeration line. The projection offers a forecast that enables the calculation of the celeration change value.	See advanced charting conventions sample chart.
5. Celeration change (CC) (aka celeration turn up or turn down)	The multiply "×" or divide "÷" value that compares the celeration of one phase to the celeration in the next phase (e.g., a celeration turn down from × 1.3 to ÷ 1.3. CC = ÷ 1.7).	Place a "CC =" in the upper middle cell of the analysis matrix with the value indicated with a "×" or "÷" sign (e.g., CC = ÷ 1.7).
6. Celeration collection	A group of three or more celerations for different performers relating to the same behavior over approximately the same time period.	Numerically identify the high, middle, and low celeration in the celeration collection and indicate the total number of celerations in the collection.
7. Bounce change (BC)	The multiply "×" or divide "÷" value that compares the bounce in one phase to the bounce in the next phase. Computed by comparing (1) the total bounce of one phase to (2) the total bounce of the next phase (e.g., a bounce change from 5.0 to × 1.4, BC = ÷ 3.6).	Place a "BC =" in the upper right cell of the analysis matrix with the value indicated with a multiply "×" or divide "÷" symbol (e.g., BC = ÷ 3.6).
8. Analysis matrix	The analysis matrix provides the numeric change information regarding the effects of the independent variable(s) on frequency, celeration, and bounce between two phases.	Place the analysis matrix between the two phases being compared. For acceleration targets place the matrix above the data. For deceleration targets place the matrix below the data.
Optional:		
9. Frequency change p-value (FCP)	The frequency change p-value is the probability that the noted change in frequency would have occurred by chance. (Use the Fisher exact probability formula to compute the p-value.)	Use "FCP =" and indicate the p-value in the lower left cell on the analysis matrix (e.g., FCP = .0001).
10. Celeration change p-value (CCP)	The celeration change p-value is the probability that the change noted in celeration would have occurred by chance. (Use the Fisher exact probability formula to compute the p-value.)	Use "CCP =" and indicate the p-value in the lower middle cell of the matrix (e.g., CCP = .0001).
11. Bounce change p-value (BCP)	The bounce change p-value is the probability that the change noted in bounce would have occurred by chance. (Use the Fisher exact probability formula to compute the p-value.)	Use "BCP =" and indicate the p-value in the lower right cell of the analysis matrix (e.g., BCP = .0001).

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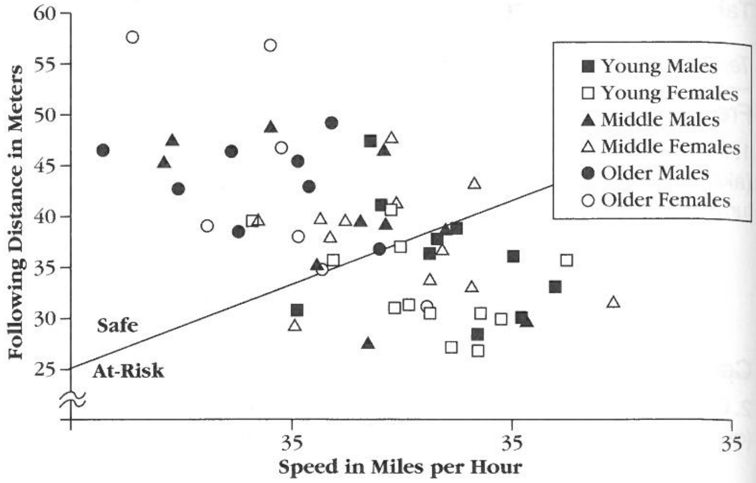


Figure 6.17 Scatterplot showing how the behavior of individuals from different demographic groups relates to a standard measure of safe driving.

From "A Technology to Measure Multiple Driving Behaviors without Self-Report or Participant Reactivity" by T. E. Boyce and E. S. Geller, 2001, *Journal of Applied Behavior Analysis, 34,* p. 49. Copyright 2001 by the Society for the Experimental Analysis of Behavior, Inc. Used by permission.

points falling along lines on the plane or clusters suggest certain relationships.

Scatterplots can reveal relationships among different subsets of data. For example, Boyce and Geller (2001) created the scatterplot shown in Figure 6.17 to see how the behavior of individuals from different demographic groups related to a ratio of driving speed and following distance that represents one element of safe driving (e.g., the proportion of data points for young males falling in the at-risk area of the graph compared to the proportion of drivers from other groups). Each data point shows a single driver's behavior in terms of speed and following distance and whether the speed and following distance combination is considered safe or at risk for accidents. Such data could be used to target interventions for certain demographic groups.

Applied behavior analysts sometimes use scatterplots to discover the temporal distribution of a target behavior (e.g., Kahng et al., 1998; Symons, McDonald, & Wehby, 1998; Touchette, MacDonald, & Langer, 1985). Touchette and colleagues described a procedure for observing and recording behavior that produces a scatterplot that graphically shows whether the behavior's occurrence is typically associated with certain time periods. The use of scatterplot recording is described further in Chapter 24.

Constructing Line Graphs

The skills required to construct effective, distortion-free graphic displays are as important as any in the behavior analyst's repertoire. As applied behavior analysis has developed, so have certain stylistic conventions and expectations regarding the construction of graphs. An effective graph presents the data accurately, completely, and clearly, and makes the viewer's task of understanding the data as easy as possible. The graph maker must strive to fulfill each of these requirements while remaining alert to features in the graph's design or construction that might create distortion and bias—either the graph maker's or that of a future viewer when interpreting the extent and nature of the behavior change depicted by the graph.

Despite the graph's prominent role in applied behavior analysis, relatively few detailed treatments of how to construct behavioral graphs have been published. Notable exceptions have been chapters by Parsonson and Baer (1978, 1986) and a discussion of graphic display tactics by Johnston and Pennypacker (1980, 1993a). Recommendations from these excellent sources and others (*Journal of Applied Behavior Analysis,* 2000; American Psychological Association, 2001; Tufte, 1983, 1990) contributed to the preparation of this section. Additionally, hundreds of graphs published in the applied behavior analysis literature were examined in an effort to discover those features that communicate necessary information most clearly.

Although there are few hard-and-fast rules for constructing graphs, adhering to the following conventions will result in clear, well-designed graphic displays consistent in format and appearance with current practice. Although most of the recommendations are illustrated by graphs presented throughout this text, Figures 6.18 and 6.19 have been designed to serve as models for most of the practices suggested here. The recommendations given here generally apply to all behavioral graphs. However, each data set and the conditions under which the data were obtained present their own challenges to the graph maker.

Drawing, Scaling, and Labeling Axes

Ratio of the Vertical and Horizontal Axes

The relative length of the vertical axis to the horizontal axis, in combination with the scaling of the axes, determines the degree to which a graph will accentuate or min-

Figure 6.18 Graph of hypothetical data illustrating a variety of conventions and guidelines for graphic display.

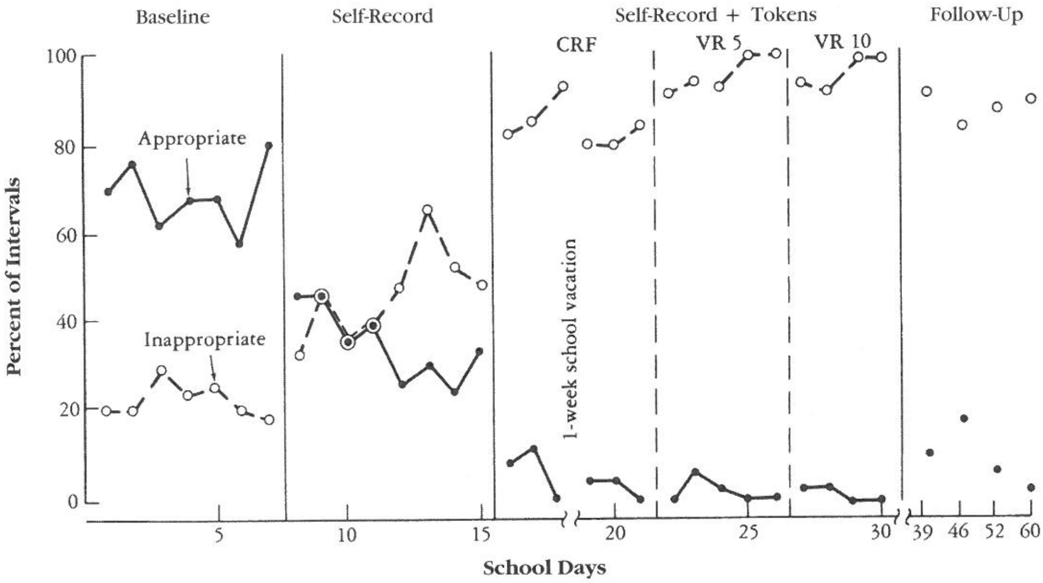


Figure 1. Percent of 10-second intervals in which an 8-year-old boy emitted appropriate and inappropriate study behaviors. Each interval was scored as appropriate, inappropriate, or neither, so the two behaviors do not always total 100%.

imize the variability in a given data set. The legibility of a graph is enhanced by a balanced ratio between the height and width so that data are neither too close together nor too spread apart. Recommendations in the behavioral literature for the ratio, or relative length, of the vertical axis to the horizontal axis range from 5:8 (Johnston & Pennypacker, 1980) to 3:4 (Katzenberg, 1975). Tufte (1983), whose book *The Visual Display of Quantitative Information* is a wonderful storehouse of guidelines and examples of effective graphing techniques, recommends a 1:1.6 ratio of vertical axis to horizontal axis.

A vertical axis that is approximately two-thirds the length of the horizontal axis works well for most behavioral graphs. When multiple sets of axes will be presented atop one another in a single figure and/or when the number of data points to be plotted on the horizontal axis is very large, the length of the vertical axis relative to the horizontal axis can be reduced (as shown in Figures 6.3 and 6.7).

Scaling the Horizontal Axis

The horizontal axis should be marked in equal intervals, with each unit representing from left to right the chronological succession of equal time periods or response opportunities in which the behavior was (or will be) measured and from which an interpretation of behavior change is to be made (e.g., days, sessions, trials). When many data points are to be plotted, it is not necessary to mark each point along the x axis. Instead, to avoid unnecessary clutter, regularly spaced points on the horizontal axis are indicated with *tic marks* numbered by 5s, 10s, or 20s.

When two or more sets of axes are stacked vertically and each horizontal axis represents the same time frame, it is not necessary to number the tic marks on the horizontal axes of the upper tiers. However, the hatch marks corresponding to those numbered on the bottom tier should be placed on each horizontal axis to facilitate comparison of performance across tiers at any given point in time (see Figure 6.4).

Representing Discontinuities of Time on the Horizontal Axis

Behavior change, its measurement, and all manipulations of treatment or experimental variables occur within and across time. Therefore, time is a fundamental variable in all experiments that should not be distorted or arbitrarily represented in a graphic display. Each equally spaced unit on the horizontal axis should represent an equal passage of time. Discontinuities in the progression of time on the horizontal axis should be indicated by a *scale break:* an open spot in the axis with a squiggly line at each end. Scale breaks on the x axis can also be used to signal periods of time when data were not collected or when regularly spaced data points represent consecutive measurements made at unequal intervals (see the

Figure 6.19 Graph of hypothetical data illustrating a variety of conventions and guidelines for graphic display.

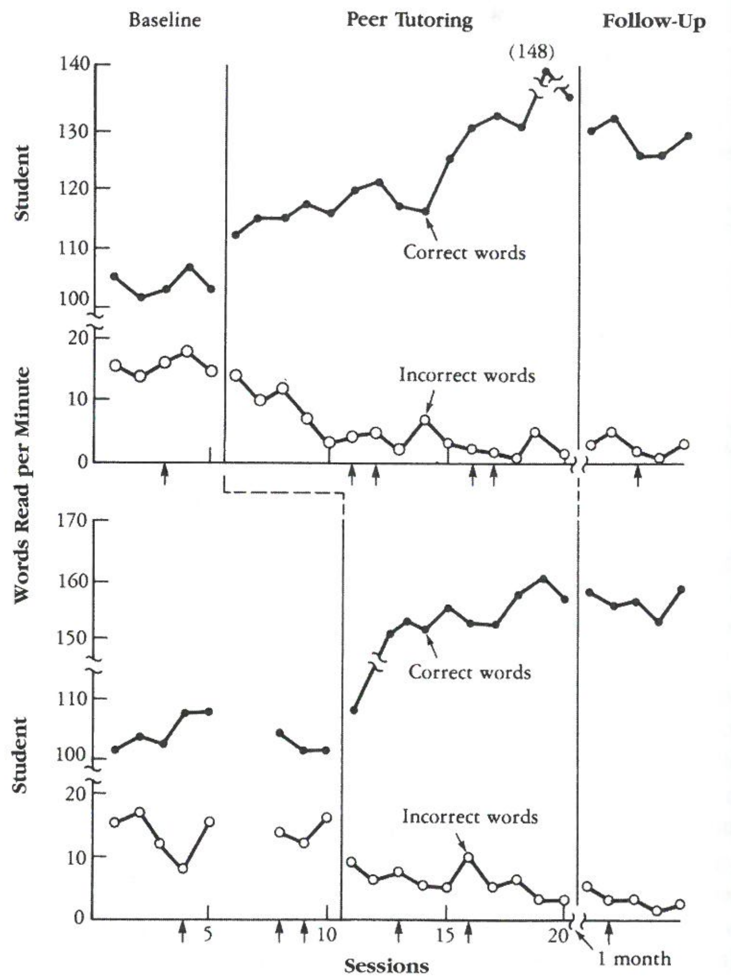


Figure 1. Number of words read correctly and incorrectly during 1-minute probes following each session. Arrows under horizontal axes indicate sessions in which student used reading material brought from home. Break in data path for Student 2 was caused by 2 days' absence.

numbering of school days for the follow-up condition in Figure 6.18).

When measurement occurs across consecutive observations (e.g., stories read, meals, interactions) rather than standard units of time, the horizontal axis still serves as a visual representation of the progression of time because the data plotted against it have been recorded one after the other. The text accompanying such a figure should indicate the real time in which the consecutive measurements were made (e.g., "Two or three peer tutoring sessions were conducted each school week"), and discontinuities in that time context should be clearly marked with scale breaks (see Figure 6.19).

Labeling the Horizontal Axis

The dimension by which the horizontal axis is scaled should be identified in a brief label printed and centered below and parallel to the axis.

Scaling the Vertical Axis

On an equal-interval graph the scaling of the vertical axis is the most significant feature of the graph in terms of its portrayal of changes in level and variability in the data. Common practice is to mark the origin at 0 (on cumulative graphs the bottom on the vertical axis must be 0) and then to mark off the vertical axis so that the full range of values represented in the data set are accommodated. Increasing the distance on the vertical axis between each unit of measurement magnifies the variability in the data, whereas contracting the units of measurement on the vertical axis minimizes the portrayal of variability in the data set. The graph maker should plot the data set against several different vertical axis scales, watching for distortion of the graphic display that might lead to inappropriate interpretations.

The social significance of various levels of behavior change for the behavior being graphed should be considered in scaling the vertical axis. If relatively small numerical changes in performance are socially significant, the y-axis scale should reflect a smaller range of values. For example, to display data most effectively from a training program in which an industrial employee's percentage of correctly executed steps in a safety checklist increased from an unsafe preintervention range of 80% to 90% to an accident-free postintervention level of 100%, the vertical axis should focus on the 80% to 100% range. On the other hand, the scaling of the vertical axis should be contracted when small numerical changes in behavior are not socially important and the degree of variability obscured by the compressed scale is of little interest.

Horizontal numbering of regularly spaced tic marks on the vertical axis facilitates use of the scale. The vertical axis should not be extended beyond the hatch mark indicating the highest value on the axis scale.

When the data set includes several measures of 0, starting the vertical axis at a point slightly above the horizontal axis keeps data points from falling directly on the axis. This produces a neater graph and helps the viewer discriminate 0-value data points from those representing measures close to 0 (see Figure 6.18).

In most instances, scale breaks should not be used on the vertical axis, especially if a data path would cross the break. However, when two sets of data with widely different and nonoverlapping ranges are displayed against the same y axis, a scale break can be used to separate the range of measures encompassed by each data set (see Figure 6.19).

In multiple-tier graphs, equal distances on each vertical axis should represent equal changes in behavior to aid the comparison of data across tiers. Also, whenever possible, similar positions on each vertical axis of multiple-tier graphs should represent similar absolute values of the dependent variable. When the differences in behavioral measures from one tier to another would result in an overly long vertical axis, a scale break can be used to highlight the difference in absolute values, again aiding a point-to-point comparison of y axis positions.

Labeling the Vertical Axis

A brief label, printed and centered to the left and parallel to the vertical axis, should identify the dimension by which the axis is scaled. On multiple-tiered graphs, one label identifying the dimension portrayed on all of the vertical axes can be centered along the axes as a group. Additional labels identifying the different behaviors (or some other relevant aspect) graphed within each set of axes are sometimes printed to the left and parallel to each vertical axis. These individual tier labels should be printed to the right of and in smaller-sized font than the label identifying the dimension by which all of the vertical axes are scaled.

Identifying Experimental Conditions

Condition Change Lines

Vertical lines extending upward from the horizontal axis indicate changes in treatment or experimental procedures. Condition change lines should be placed after (to the right of) the data point representing the last measure prior to the change in conditions signified by the line and before (to the left of) the data point representing the first measure obtained after the change in procedure. In this way data points fall clearly on either side of change lines and never on the lines themselves. Drawing condition change lines to a height equal to the height of the vertical axis helps the viewer estimate the value of data points near the top of the vertical axis range.

Condition change lines can be drawn with either solid or dashed lines. However, when an experiment or a treatment program includes relatively minor changes within an ongoing condition, a combination of solid and dashed lines should be used to distinguish the major and minor changes in conditions. For example, the solid lines in Figure 6.18 change from baseline, to self-record, to self-record + tokens, to follow-up conditions, and dashed lines indicate changes in the schedule of reinforcement from CRF, to VR 5, to VR 10 within the self-record + tokens condition.

When the same manipulation of an independent variable occurs at different points along the horizontal axes of multiple-tiered graphs, a dog-leg connecting the condition change lines from one tier to the next makes it easy to follow the sequence and timing of events in the experiment (see Figure 6.19).

Unplanned events that occur during an experiment or treatment program, as well as minor changes in procedure that do not warrant a condition change line, can be indicated by placing small arrows, asterisks, or other symbols next to the relevant data points (see Figure 6.6) or just under the x axis (see Figure 6.19). The figure caption should explain any special symbols.

Condition Labels

Labels identifying the conditions in effect during each period of an experiment are centered above the space delineated by the condition change lines. Whenever space permits, condition labels should be parallel to the horizontal axis. Labels should be brief but descriptive (e.g., *Contingent Praise* is preferable to *Treatment*), and the labels should use the same terms or phrases used in the accompanying text describing the condition. Abbreviations may be used when space or design limitations prohibit printing the complete label. A single condition label should be placed above and span across labels identifying minor changes within that condition (see Figure 6.18). Numbers are sometimes added to condition labels to indicate the number of times the condition has been in effect during the study (e.g., Baseline 1, Baseline 2).

Plotting Data Points and Drawing Data Paths

Data Points

When graphing data by hand, behavior analysts must take great care to ensure that they plot each data point exactly on the coordinate of the horizontal and vertical axis values of the measurement it represents. The inaccurate placement of data points is an unnecessary source of error in graphic displays, which can lead to mistakes in clinical judgment and/or experimental method. Accurate placement is aided by careful selection of graph paper with grid lines sized and spaced appropriately for the data to be plotted. When many different values must be plotted within a small distance on the vertical axis, a graph paper with many grid lines per inch should be used.[9]

Should a data point fall beyond the range of values described by the vertical axis scale, it is plotted just above the scale it transcends with the actual value of the measurement printed in parentheses next to the data point. Breaks in the data path leading to and from the off-the-scale data point also help to highlight its discrepancy (see Figure 6.19, Session 19).

Data points should be marked with bold symbols that are easily discriminated from the data path. When only one set of data is displayed on a graph, solid dots are most often used. When multiple data sets are plotted on the same set of axes, a different geometric symbol should be used for each set of data. The symbols for each data set should be selected so that the value of each data point can be determined when data points fall near or on the same coordinates on the graph (see Figure 6.18, Sessions 9–11).

Data Paths

Data paths are created by drawing a straight line from the center of each data point in a given data set to the center of the next data point in the same set. All data points in a given data set are connected in this manner with the following exceptions:

- Data points falling on either side of a condition change line are not connected.
- Data points should not be connected across a significant span of time in which behavior was not measured. To do so implies that the resultant data path represents the level and trend of the behavior during the span of time in which no measurement was conducted.
- Data points should not be connected across discontinuities of time in the horizontal axis (see Figure 6.18, 1-week school vacation).
- Data points on either side of a regularly scheduled measurement period in which data were not collected or were lost, destroyed, or otherwise not available (e.g., participant's absence, recording equipment failure) should not be joined together (see Figure 6.18, baseline condition of bottom graph).
- Follow-up or postcheck data points should not be connected with one another (see Figure 6.18) unless they represent successive measures spaced in time in the same manner as measures obtained during the rest of the experiment (see Figure 6.19).
- If a data point falls beyond the values described by the vertical axis scale, breaks should be made in the data path connecting that data point with those that fall within the described range (Figure 6.19, top graph, Session 19 data point).

When multiple data paths are displayed on the same graph, different styles of lines, in addition to different symbols for the data points, may be used to help distinguish one data path from another (see Figure 6.19). The behavior represented by each data path should be clearly identified, either by printed labels with arrows drawn to the data path (see Figures 6.18 and 6.19) or by a legend showing models of the symbols and line styles (see Figure 6.13). When two data sets travel the same path, their lines should be drawn close to and parallel with one another to help clarify the situation (see Figure 6.18, Sessions 9–11).

Writing the Figure Caption

Printed below the graph, the figure caption should give a concise but complete description of the figure. The caption should also direct the viewer's attention to any fea-

[9]Although most graphs published in behavior analysis journals since the mid-1990s were constructed with computer software programs that ensure precise placement of data points, knowing how to draw graphs by hand is still an important skill for applied behavior analysts, who often use hand-drawn graphs to make treatment decisions on a session-by-session basis.

tures of the graph that might be overlooked (e.g., scale changes) and should explain the meaning of any added symbols representing special events.

Printing Graphs

Graphs should be printed in only one color—black. Although the use of color can enhance the attractiveness of a visual display and can effectively highlight certain features, it is discouraged in the scientific presentation of data. Every effort must be made to let the data stand on their own. The use of color can encourage perceptions of performance or experimental effects that differ from perceptions of the same data displayed in black. The fact that graphs and charts may be reproduced in journals and books is another reason for using black only.

Constructing Graphs with Computer Software

Software programs for producing computer-generated graphs have been available and are becoming both increasingly sophisticated and easier to use. Most of the graphs displayed throughout this book were constructed with computer software. Even though computer graphics programs offer a tremendous time savings over hand-plotted graphs, careful examination should be made of the range of scales available and the printer's capability for both accurate data point placement and precise printing of data paths.

Carr and Burkholder (1998) provided an introduction to creating single-subject design graphs with Microsoft Excel. Silvestri (2005) wrote detailed, step-by-step instructions for creating behavioral graphs using Microsoft Excel. Her tutorial can be found on the companion Web site that accompanies this text, www.prenhall.com/cooper.

Interpreting Graphically Displayed Behavioral Data

The effects of an intervention that produces dramatic, replicable changes in behavior that last over time are readily seen in a well-designed graphic display. People with little or no formal training in behavior analysis can read the graph correctly in such cases. Many times, however, behavior changes are not so large, consistent, or durable. Behavior sometimes changes in sporadic, temporary, delayed, or seemingly uncontrolled ways; and sometimes behavior may hardly change at all. Graphs displaying these kinds of data patterns often reveal equally important and interesting subtleties about behavior and its controlling variables.

Behavior analysts employ a systematic form of examination known as **visual analysis** to interpret graphically displayed data. Visual analysis of data from an applied behavior analysis study is conducted to answer two questions: (a) Did behavior change in a meaningful way, and (b) if so, to what extent can that change in behavior be attributed to the independent variable? Although there are no formalized rules for visual analysis, the dynamic nature of behavior, the scientific and technological necessity of discovering effective interventions, and the applied requirement of producing socially meaningful levels of performance all combine to focus the behavior analyst's interpretive attention on certain fundamental properties common to all behavioral data: (a) the extent and type of variability in the data, (b) the level of the data, and (c) trends in the data. Visual analysis entails an examination of each of these characteristics both within and across the different conditions and phases of an experiment.

As Johnston and Pennypacker (1993b) so aptly noted, "It is impossible to interpret graphic data without being influenced by various characteristics of the graph itself" (p. 320). Therefore, before attempting to interpret the meaning of the data displayed in a graph, the viewer should carefully examine the graph's overall construction. First, the figure legend, axis labels, and all condition labels should be read to determine a basic understanding of what the graph is about. The viewer should then look at the scaling of each axis, taking note of the location, numerical value, and relative significance of any scale breaks.

Next, a visual tracking of each data path should be made to determine whether data points are properly connected. Does each data point represent a single measurement or observation, or are the data "blocked" such that each data point represents an average or some other summary of multiple measurements? Do the data show the performance of an individual subject or the average performance of a group of subjects? If blocked or group data are displayed, is a visual representation of the range or variation of scores provided (e.g., Armendariz & Umbreit, 1999; Epstein et al., 1981); or do the data themselves allow determination of the amount of variability that was collapsed in the graph? For example, if the horizontal axis is scaled in weeks and each data point represents a student's average score for a week of daily five-word spelling tests, data points falling near 0 or at the top end of the closed scale, such as 4.8, pose little problem because they can be the result of only minimal variability in the daily scores for that week. However, data points near the center of the scale, such as 2 to 3, can result from either stable or highly variable performance.

If the viewer suspects distortion produced by a graph's construction, interpretive judgments of the data should be withheld until the data are replotted on a new set of axes. Distortion due to a loss of important data features in summarizing is not so easily remedied. The viewer must consider the report incomplete and forestall any interpretive conclusions until he has access to the raw data.

Only when the viewer is satisfied that the graph is properly constructed and does not visually distort the behavioral and environmental events it represents, should the data themselves be examined. The data are then inspected to find what they reveal about the behavior measured during each condition of the study.

Visual Analysis within Conditions

Data within a given condition are examined to determine (a) the number of data points, (b) the nature and extent of variability in the data, (c) the absolute and relative level of the behavioral measure, and (d) the direction and degree of any trend(s) in the data.

Number of Data Points

First, the viewer should determine the quantity of data reported during each condition. This entails a simple counting of data points. As a general rule, the more measurements of the dependent variable per unit of time and the longer the period of time in which measurement occurred, the more confidence one can have in the data path's estimation of the true course of behavior change (given, of course, a valid and accurate observation and measurement system).

The number of data points needed to provide a believable record of behavior during a given condition also depends on how many times the same condition has been repeated during the study. As a rule, fewer data points are needed in subsequent replications of an experimental condition if the data depict the same level and trend in performance that were noted in earlier applications of the condition.

The published literature of applied behavior analysis also plays a part in determining how many data points are sufficient. In general, less lengthy phases are required of experiments investigating relations between previously studied and well-established variables if the results are also similar to those of the previous studies. More data are needed to demonstrate new findings, whether or not new variables are under investigation.

There are other exceptions to the rule of the-more-data-the-better. Ethical concerns do not permit the repeated measurement of certain behaviors (e.g., self-injurious behavior) under an experimental condition in which there is little or no expectation for improvement (e.g., during a no-treatment baseline condition or a condition intended to reveal variables that exacerbate problem behavior). Also, there is little purpose in repeated measurement in situations in which the subject cannot logically perform the behavior (e.g., measuring the number of correct answers to long division problems when concurrent observations indicate that the student has not learned the necessary component skills of multiplication and subtraction). Nor are many data points required to demonstrate that behavior did not occur when in fact it had no opportunity to occur.

Familiarity with the response class measured and the conditions under which it was measured may be the graph viewer's biggest aid in determining how many data points constitute believability. The quantity of data needed in a given condition is also partly determined by the analytic tactics employed in a given study. Experimental design tactics are described in Chapters 7 through 10.

Variability

How often and the extent to which multiple measures of behavior yield different outcomes is called **variability.** A high degree of variability within a given condition usually indicates that the researcher or practitioner has achieved little control over the factors influencing the behavior. (An important exception to this statement is when the purpose of an intervention is to produce a high degree of variability.) In general, the greater the variability within a given condition, the greater the number of data points that are necessary to establish a predictable pattern of performance. By contrast, fewer data points are required to present a predictable pattern of performance when those data reveal relatively little variability.

Level

The value on the vertical axis scale around which a set of behavioral measures converge is called **level.** In the visual analysis of behavioral data, level is examined within a condition in terms of its absolute value (mean, median, and/or range) on the *y*-axis scale, the degree of stability or variability, and the extent of change from one level to another. The graphs in Figure 6.20 illustrate four different combinations of level and variability.

The mean level of a series of behavioral measures within a condition can be graphically illustrated by the addition of a *mean level line:* a horizontal line drawn through a series of data points within a condition at that point on the vertical axis equaling the average value of the

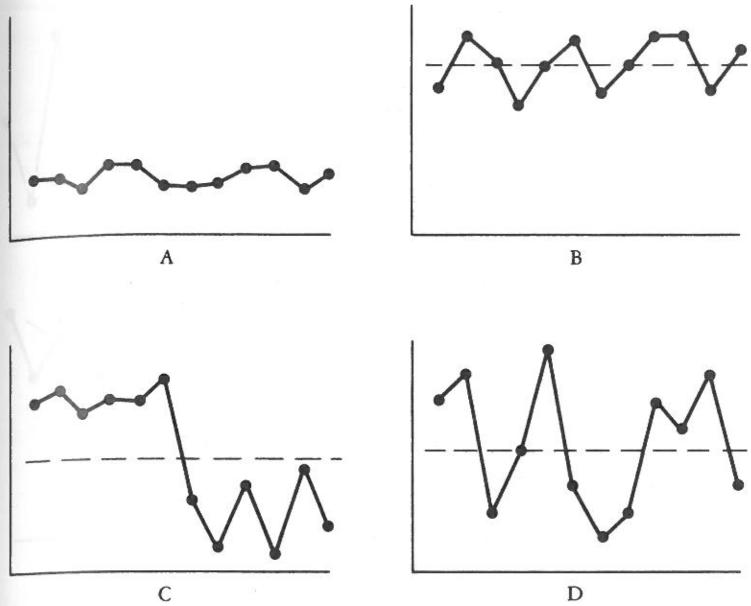


Figure 6.20 Four data paths illustrating (A) a low, stable level of responding; (B) a high, variable level of responding; (C) an initially high, stable level of responding followed by a lower, more variable level of responding; and (D) an extremely variable pattern of responding not indicative of any overall level of responding. Dashed horizontal lines on graphs B, C, and D represent the mean levels of responding.

series of measures (e.g., Gilbert, Williams, & McLaughlin, 1996). Although mean level lines provide an easy-to-see summary of average performance within a given condition or phase, they should be used and interpreted with caution. With highly stable data paths, mean level lines pose no serious drawbacks. However, the less variability there is within a series of data points, the less need there is for a mean level line. For instance, a mean level line would serve little purpose in Graph A in Figure 6.20. And although mean level lines have been added to Graphs B, C, and D in Figure 6.20, Graph B is the only one of the three for which a mean level line provides an appropriate visual summary of level. The mean level line in Graph C is not representative of any measure of behavior taken during the phase. The data points in Graph C show a behavior best characterized as occurring at two distinct levels during the condition and beg for an investigation of the factor(s) responsible for the clear change in levels. The mean level line in Graph D is also inappropriate because the variability in the data is so great that only 4 of the 12 data points fall close to the mean level line.

A *median level line* is another method for visually summarizing the overall level of behavior in a condition. Because a median level line represents the most typical performance within a condition, it is not so influenced by one or two measures that fall far outside the range of the remaining measures. Therefore, one should use a median level line instead of a mean level line to graphically represent the central tendency of a series of data points that include several outliers, either high or low.

Change in level within a condition is determined by calculating the difference in absolute values on the *y* axis between the first and last data points within the condition. Another method, somewhat less influenced by variability in the data, is to compare the difference between the median value of the first three data points in the condition with the median value of the final three data points in the condition (Koenig & Kunzelmann, 1980).

Trend

The overall direction taken by a data path is its **trend.** Trends are described in terms of their direction (increasing, decreasing, or zero trend), degree or magnitude, and extent of variability of data points around the trend. The graphs in Figure 6.21 illustrate a variety of trends. The direction and degree of trend in a series of graphed data points can be visually represented by a straight line drawn through the data called a *trend line* or *line of progress.* Several methods for calculating and fitting trends lines to a series of data have been developed. One can simply inspect the graphed data and draw a straight line that visually provides the best fit through the data. For this freehand method, Lindsley (1985) suggested ignoring one or two data points that fall well beyond the range of the remaining values in a data series and fitting the trend line to the remaining scores. Although the freehand method is the fastest way of drawing trend lines and can be useful for the viewer of a published graph, hand-drawn trend lines may not always result in an accurate representation of trend and are typically not found in graphs of published studies.

Trend lines can also be calculated using a mathematical formula called the ordinary least-squares linear

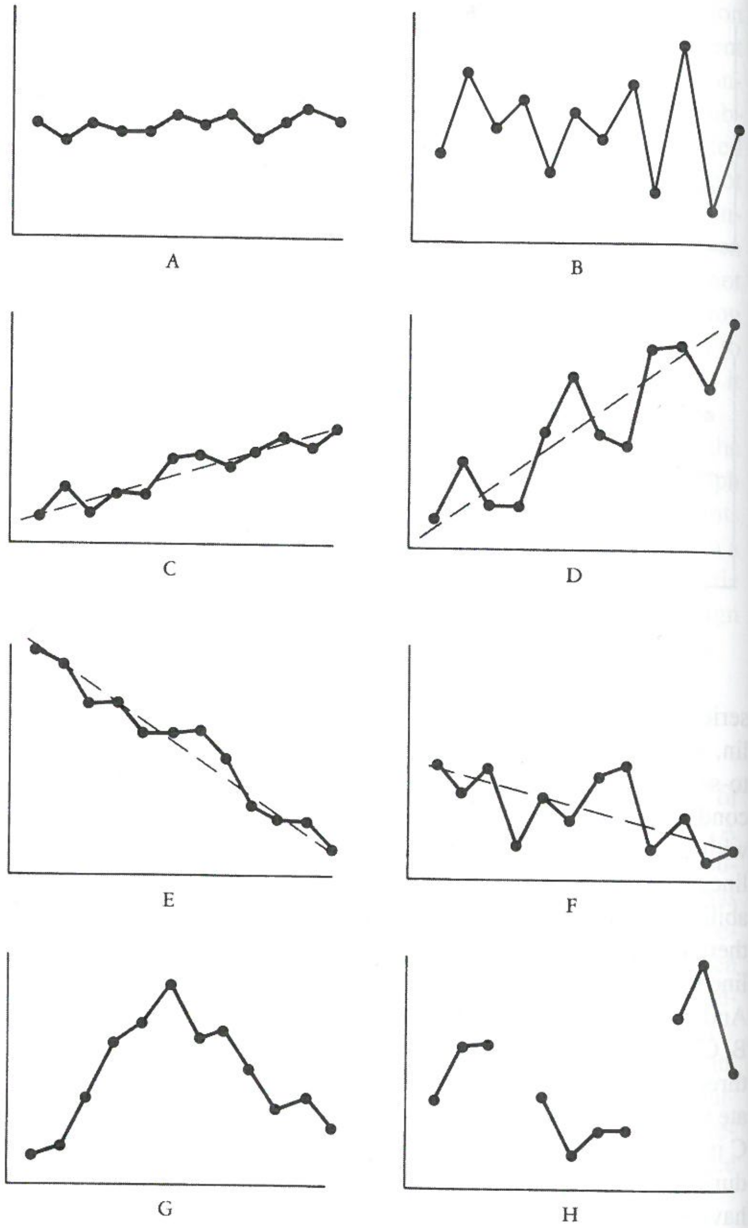


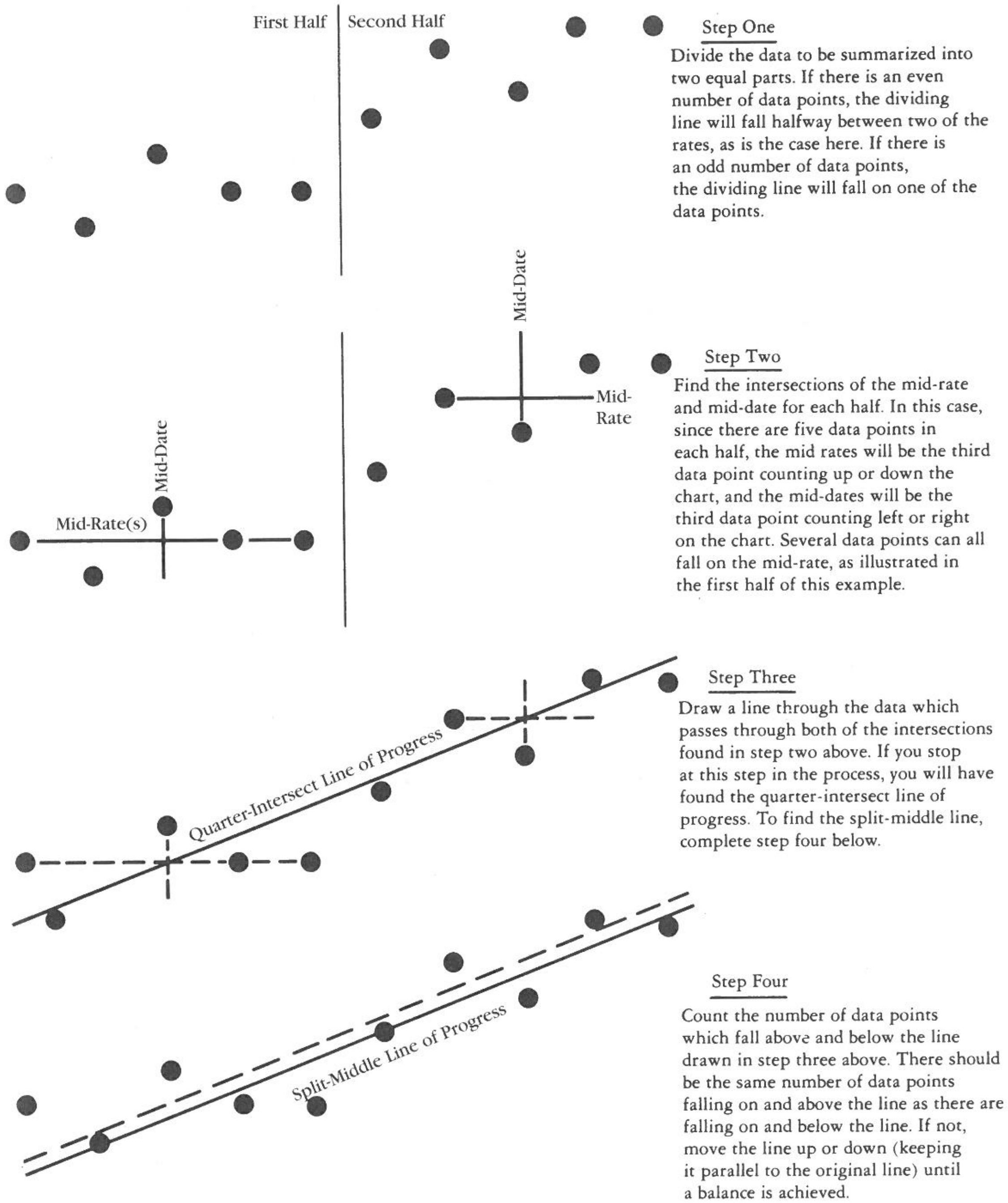
Figure 6.21 Data patterns indicating various combinations of trend direction, degree, and variability: (A) zero trend, high stability; (B) zero trend, high variability; (C) gradually increasing stable trend; (D) rapidly increasing variable trend; (E) rapidly decreasing stable trend; (F) gradually decreasing variable trend; (G) rapidly increasing trend followed by rapidly decreasing trend; (H) no meaningful trend, too much variability and missing data. Split-middle lines of progress have been added to Graphs C–F.

regression equation (McCain & McCleary, 1979; Parsonson & Baer, 1978). Trend lines determined in this fashion have the advantage of complete reliability: The same trend line will always result from the same data set. The disadvantage of this method is the many mathematical operations that must be performed to calculate the trend line. A computer program that can perform the equation can eliminate the time concern in calculating a least-squares trend line.

A method of calculating and drawing lines of progress that is more reliable than the freehand method and much less time-consuming than linear regression methods is the **split-middle line of progress.** The split-middle technique was developed by White (1971, 2005) for use with rate data plotted on semilogarithmic charts, and it has proven a useful technique for predicting future behavior from such data. Split-middle lines of progress can also be drawn for data plotted against an equal-interval vertical axis, but it must be remembered that such a line is only an estimate that summarizes the overall trend (Bailey, 1984). Figure 6.22 provides a step-by-step illustration of how to draw split-middle lines of progress. A trend line cannot be drawn by any method through a series of data points spanning a scale break in the vertical axis and generally should not be drawn across scale breaks in the horizontal axis.

The specific degree of acceleration or deceleration of trends in data plotted on semilogarithmic charts can be quantified in numerical terms. For example, on the daily Standard Celeration Chart a "times-2" celeration means

Figure 6.22 How to draw a split-middle line of progress through a series of graphically displayed data points.



Adapted from *Exceptional Teaching,* p. 118, by O. R. White and N. G. Haring, 1980, Columbus, OH: Charles E. Merrill. Copyright 1980 by Charles E. Merrill. Used by permission.

that the response rate is doubling each week, and a "times-1.25" means that the response rate is accelerating by a factor of one fourth each week. A "divide-by-2" celeration means that each week the response rate will be one half of what it was the week before, and a "divide-by-1.5" means that the frequency is decelerating by one third each week.

There is no direct way to determine visually from data plotted on equal-interval charts the specific rates at which trends are increasing or decreasing. But visual comparison of trend lines drawn through data on equal-interval charts can provide important information about the relative rates of behavior change.

A trend may be highly stable with all of the data points falling on or near the trend line (see Figure 6.21, Graphs C and E). Data paths can also follow a trend even though a high degree of variability exists among the data points (see Figure 6.21, Graphs D and F).

Visual Analysis between Conditions

After inspection of the data within each condition or phase of a study, visual analysis proceeds with a comparison of data between conditions. Drawing proper conclusions entails comparing the previously discussed properties of behavioral data—level, trend, and stability/variability—between different conditions and among similar conditions.

A condition change line indicates that an independent variable was manipulated at a given point in time. To determine whether an immediate change in behavior occurred at that point in time, one needs to examine the difference between the last data point before the condition change line and the first data point in the new condition.

The data are also examined in terms of the overall level of performance between conditions. In general, when all data points in one condition fall outside the range of values for all data points in an adjacent condition (that is, there is no overlap of data points between the highest values obtained in one condition and the lowest values obtained in the other condition), there is little doubt that behavior changed from one condition to the next. When many data points in adjacent conditions overlap one another on the vertical axis, less confidence can be placed in the effect of the independent variable associated with the change in conditions.[10]

Mean or median level lines can be helpful in examining the overall level between conditions. However, using mean or median level lines to summarize and compare the overall central tendency of data across conditions poses two serious problems. First, the viewer of such a visual display must guard against letting "apparently large differences among measures of central tendency visually overwhelm the presence of equally large amounts of uncontrolled variability" (Johnston & Pennypacker, 1980, p. 351). Emphasis on mean changes in performance in a graphic display can lead the viewer to believe that a greater degree of experimental control was obtained than is warranted by the data. In the top graph of Figure 6.23 half of the data points in Condition B fall within the range of values of the measures taken during Condition A, but the mean level lines suggest a clear change in behavior. Second, measures of central tendency can obscure important trends in the data that warrant interpretations other than those suggested by the central tendency indicators. Although a mean or median line accurately represents the average or typical performance, neither provides any indication of increasing or decreasing performance. In the bottom graph of Figure 6.23, for example, the mean line suggests a higher level of performance in Condition B than in Condition A, but an examination of trend yields a very different picture of behavior change within and between Conditions A and B.

Those analyzing behavioral data should also note any changes in level that occur after a new condition has been in place for some time and any changes in level that occur early in a new condition but are later lost. Such delayed or temporary effects can indicate that the independent variable must be in place for some time before behavior changes, or that the temporary level change was the result of an uncontrolled variable. Either case calls for further investigation in an effort to isolate and control relevant variables.

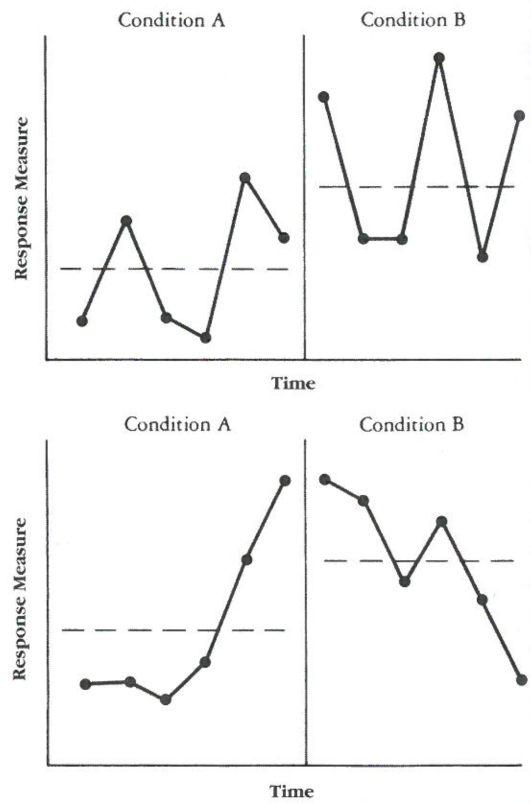


Figure 6.23 Inappropriate use of mean level lines, encouraging interpretation of a higher overall level of responding in Condition B when extreme variability (top graph) and trends (bottom graph) warrant different conclusions.

[10]Whether a documented change in behavior should be interpreted as a function of the independent variable depends on the experimental design used in the study. Strategies and tactics for designing experiments are presented in Chapters 7 through 10.

Visual analysis of data between adjacent conditions includes an examination of the trends exhibited by the data in each condition to determine whether the trend found in the first condition changed in direction or slope during the subsequent condition. In practice, because each data point in a series contributes to level and trend, the two characteristics are viewed in conjunction with one another. Figure 6.24 presents stylized data paths illustrating four basic combinations of change or lack of change in level and trend between adjacent conditions. Of course, many other data patterns could display the same characteristics. Idealized, straight-line data paths that eliminate the variability found in most repeated measures of behavior have been used to highlight level and trend.

Visual analysis includes not only an examination and comparison of changes in level and trend between adjacent conditions, but also an examination of performance across similar conditions. Interpreting what the data from an applied behavior *analysis* mean requires more than visual analysis and the identification and description of level, trend, and variability. When behavior change is demonstrated over the course of a treatment program or research study, the next question to be asked is, Was the change in behavior a function of the treatment or experimental variables? The remaining chapters of Part Three describe strategies and tactics of experimental design used by applied behavior analysts in an effort to provide a meaningful answer.

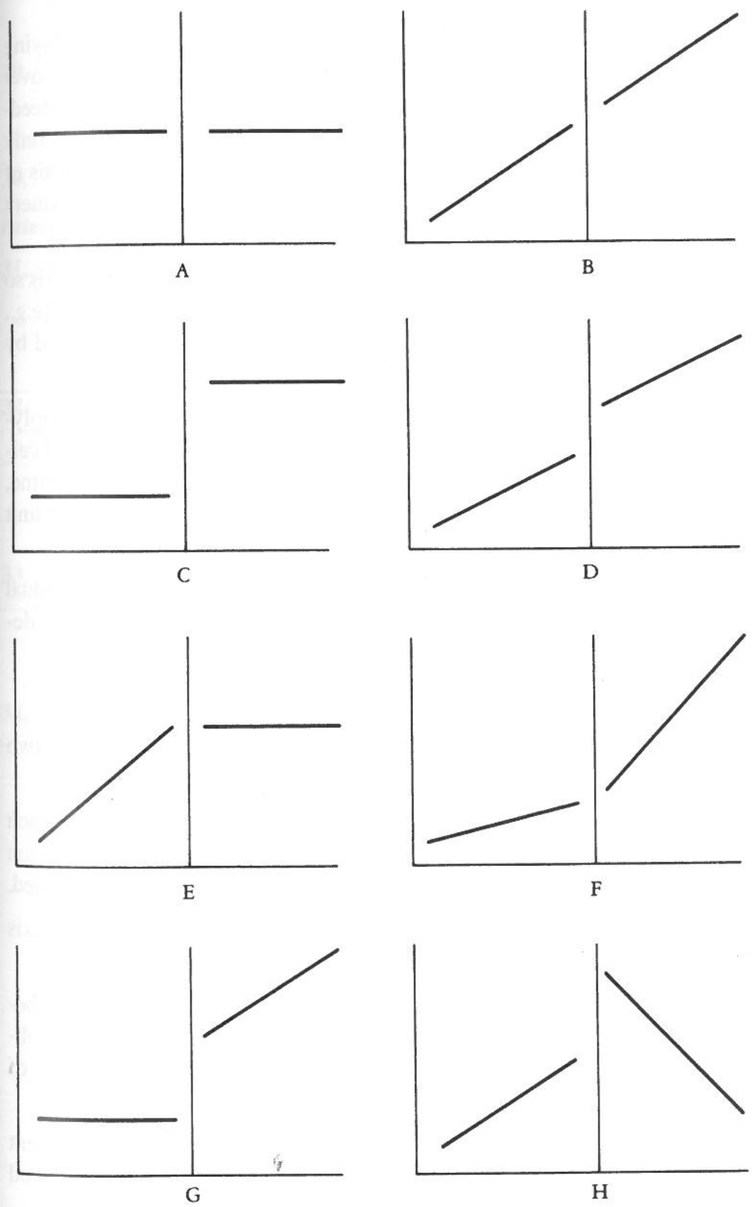


Figure 6.24 Stylized data paths illustrating the different combinations of change or lack of change in level and trend between two adjacent conditions: Graphs A and B show no change in either level or trend between the two conditions, Graphs C and D show changes in level and no change in trend, Graphs E and F depict no immediate change in level and a change in trend, and Graphs G and H reveal change in both level and trend.

From "Time-Series Analysis in Operant Research" by R. R. Jones, R. S. Vaught, and M. R. Weinrott, 1977, *Journal of Applied Behavior Analysis*, 10, p. 157. Copyright 1977 by the Society for the Experimental Analysis of Behavior, Inc. Adapted by permission.

Summary

1. Applied behavior analysts document and quantify behavior change by direct and repeated measurement of behavior, and the product of those measurements called *data.*
2. Graphs are relatively simple formats for visually displaying relationships among and between a series of measurements and relevant variables.

Purpose and Benefits of Graphic Display of Behavioral Data

3. Graphing each measure of behavior as it is collected provides the practitioner or researcher with an immediate and ongoing visual record of the participant's behavior, allowing treatment and experimental decisions to be responsive to the participant's performance.
4. Direct and continual contact with the data in a readily analyzable format enables the practitioner or researcher to identify and investigate interesting variations in behavior as they occur.
5. As a judgmental aid for interpreting experimental results, graphic display is a fast, relatively easy-to-learn method that imposes no arbitrary levels of significance for evaluating behavior change.
6. Visual analysis of graphed data is a conservative method for determining the significance of behavior change; only variables able to produce meaningful effects repeatedly are considered significant, and weak and unstable variables are screened out.
7. Graphs enable and encourage independent judgments of the meaning and significance of behavior change by others.
8. Graphs can serve as effective sources of feedback to the people whose behavior they represent.

Types of Graphs Used in Applied Behavior Analysis

9. Line graphs, the most commonly used format for the graphic display of behavioral data, are based on the Cartesian plane, a two-dimensional area formed by the intersection of two perpendicular lines.
10. Major parts of the simple line graph are the horizontal axis (also called the *x* axis), the vertical axis (also called the *y* axis), condition change lines, condition labels, data points, the data path, and the figure caption.
11. Graphs with multiple data paths on the same set of axes are used in applied behavior analysis to show (a) two or more dimensions of the same behavior, (b) two or more different behaviors, (c) the same behavior under different and alternating experimental conditions, (d) changes in target behavior relative to the changing values of an independent variable, and (e) the behavior of two or more participants.
12. A second vertical axis, which is drawn on the right-hand side of the horizontal axis, is sometimes used to show different scales for multiple data paths.
13. Bar graphs are used for two primary purposes: (a) to display discrete data not related by an underlying dimension that can be used to scale the horizontal axis and (b) to summarize and enable easy comparison of the performance of a participant or group of participants during the different conditions of an experiment.
14. Each data point on a cumulative record represents the total number of responses emitted by the subject since measurement began. The steeper the slope of the data path on a cumulative graph, the higher the response rate.
15. Overall response rate refers to the average rate of response over a given time period; a local response rate refers to the rate of response during a smaller period of time within a larger period for which an overall response rate has been given.
16. Cumulative records are especially effective for displaying data when (a) the total number of responses made over time is important, (b) the graph is used as a source of feedback to the subject, (c) the target behavior can occur only once per measurement period, and (d) a fine analysis of a single instance or portions of data from an experiment is desired.
17. Semilogarithmic charts use a logarithmic-scaled *y* axis so that changes in behavior that are of equal proportion (e.g., doublings of the response measure) are represented by equal distances on the vertical axis.
18. The Standard Celeration Chart is a six-cycle multiply-divide graph that enables the standardized charting of celeration, a linear measure of frequency change across time, a factor by which frequency multiplies or divides per unit of time.
19. A scatterplot shows the relative distribution of individual measures in a data set with respect to the variables depicted by the *x* and *y* axes.

Constructing Line Graphs

20. The vertical axis is drawn to a length approximately two thirds that of the horizontal axis.
21. The horizontal axis is marked off in equal intervals, each representing from left to right the chronological succession of equal time periods within which behavior was measured.
22. Discontinuities of time are indicated on the horizontal axis by scale breaks.
23. The vertical axis is scaled relative to the dimension of behavior measured, the range of values of the measures obtained, and the social significance of various levels of change in the target behavior.
24. Condition change lines indicate changes in the treatment program or manipulations of an independent variable and are drawn to the same height as the vertical axis.

25. A brief, descriptive label identifies each condition of an experiment or behavior change program.

26. Data points should be accurately placed with bold, solid dots. When multiple data paths are used, different geometric symbols are used to distinguish each data set.

27. Data paths are created by connecting successive data points with a straight line.

28. Successive data points should not be connected when (a) they fall on either side of a condition change line; (b) they span a significant period of time in which behavior was not measured; (c) they span discontinuities of time on the horizontal axis; (d) they fall on either side of a regularly scheduled measurement period in which data were not collected or were lost, destroyed, or otherwise not available; (e) they fall in a follow-up or postcheck period that is not regularly spaced in time in the same manner as the rest of the study; or (f) one member of the pair falls outside the range of values described by the vertical axis.

29. The figure caption provides a concise but complete description of the graph, giving all of the information needed to interpret the display.

30. Graphs should be printed in black ink only.

Interpreting Graphically Displayed Behavioral Data

31. Visual analysis of graphed data attempts to answer two questions: (a) did a socially meaningful change in behavior take place, and (b) if so, can the behavior change be attributed to the independent variable?

32. Before beginning to evaluate the data displayed in a graph, a careful examination of the graph's construction should be undertaken. If distortion is suspected from the features of the graph's construction, the data should be replotted on a new set of axes before interpretation is attempted.

33. Blocked data and data representing the average performance of a group of subjects should be viewed with the understanding that significant variability may have been lost in the display.

34. Visual analysis of data within a given condition focuses on the number of data points, the variability of performance, the level of performance, and the direction and degree of any trends in the data.

35. As a general rule, the more data in a condition and the greater the stability of those data, the more confidence one can place in the data path's estimate of behavior during that time. The more variability in the behavioral measures during a condition, the greater the need for additional data.

36. *Variability* refers to the frequency and degree to which multiple measures of behavior yield different outcomes. A high degree of variability within a given condition usually indicates that little or no control has been achieved over the factors influencing the behavior.

37. *Level* refers to the value on the vertical axis around which a series of data points converges. When the data in a given condition all fall at or near a specific level, the behavior is considered stable with respect to level; to the extent that the behavioral measures vary considerably from one to another, the data are described as showing variability with respect to level. In cases of extreme variability, no particular level of performance is evidenced.

38. Mean or median level lines are sometimes added to graphic displays to represent the overall average or typical performance during a condition. Mean and median level lines should be used and interpreted with care because they can obscure important variability and trends in the data.

39. *Trend* refers to the overall direction taken by a data path; trends are described in terms of their direction (increasing, decreasing, or zero trend), degree (gradual or steep), and the extent of variability of data points around the trend.

40. Trend direction and degree can be visually represented by drawing a trend line, or line of progress, through a series of data points. Trend lines can be drawn freehand, using the least-squares regression equation, or using a method called the split-middle line of progress. Split-middle lines of progress can be drawn quickly and reliably and have proven useful in analyzing behavior change.

41. Visual analysis of data across conditions determines whether change in level, variability, and/or trend occurred and to what extent any changes were significant.