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Bars and lines: A study of graphic communication

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Interpretations of graphs seem to be rooted in principles of cognitive naturalness and information processing rather than arbitrary correspondences. These predict that people should more readily associate bars with discrete comparisons between data points because bars are discrete entities and facilitate point estimates. They should more readily associate lines with trends because lines connect discrete entities and directly represent slope. The predictions were supported in three experiments—two examining comprehension and one production. The correspondence does not seem to depend on explicit knowledge of rules. Instead, it may reflect the influence of the communicative situation as well as the perceptual properties of graphs.

Graphs are a pervasive species of cognitive artifact, used both to reason about data and to communicate them. There are a large number of ways to portray any particular set of data, yet common usage exhibits regular patterns. One such pattern is the use of bar graphs to depict comparisons among discrete data points, and line graphs to depict trends. This pattern does not seem to be arbitrary. On the one hand, it fits with the way in which people use space to convey meaning. On the other hand, it fits with the ease with which people extract information from graphics.

We will call this pattern the *bar–line message correspondence*, because it relates the type of graph to the conceptual message depicted. In the following, we describe how the bar–line message correspondence could originate from biases in the perceptual and cognitive abilities of graph users. We will then present data documenting the correspondence for both interpreters and authors of graphs. Finally, we interpret the findings in the context of the larger situation in which graphs are used to communicate.

Cognitive Naturalness

Many conventions of graphic communication have been invented and reinvented across cultures and by children, suggesting that they derive from cognitively natural ways of using space to convey meaning (Tversky, 1995). Some support for this comes from research on production and comprehension of graphic displays. In producing graphic representations of temporal, quantitative, and preference relations, children across cultures line up dots that they perceive as representing levels of an underlying dimension but do not line up dots that they do not perceive as related dimensionally (Tversky, Kugelmass, & Winter, 1991). In selecting graphic displays for conveying various sorts of information, adults prefer bars for conveying detailed information about individual data points and lines for conveying trends (Levy, Zacks, Tversky, & Schiano, 1996). The Gestalt principles underlying figural perception support the naturalness of bars for categorical information and lines for ordinal or interval data. Bars are like containers or fences, which enclose one set of entities and separate them from others. Lines are like paths or outstretched hands, which connect separate entities. Consistent with this view, Carswell and Wickens (1990) found that in simple line graphs of two data points, the two data values were processed as *configural* dimensions, allowing viewers to perceptually integrate information from the two dimensions.

Information-Processing Models of Graphical Perception

Graphs are processed and produced, so ease of processing and naturalness of production should affect choices. According to Pinker's (1990) model of graph comprehension, a reader first constructs a visual description of the display, which is constrained by several factors, including Gestalt laws of grouping and prior experience. From the visual description, the reader constructs conceptual messages, propositions about variables depicted in the graph. High-level inferential processes are available to operate on conceptual messages. Following Bertin (1983), Pinker argues, "different types of graphs are not easier or more difficult across the board, but are easier or more difficult depending on the particular class of information that is to be extracted" (Pinker, 1990, p. 111). The theory (in accordance with Gestalt principles) predicts that it should be easier to make discrete comparisons between individual data points from bar graphs and easier to make trend assessments from line graphs.[1] Absolute values should be easier to discern when values are presented separately, as in bars, whereas trends should be easier to discern when values are connected, as in lines.

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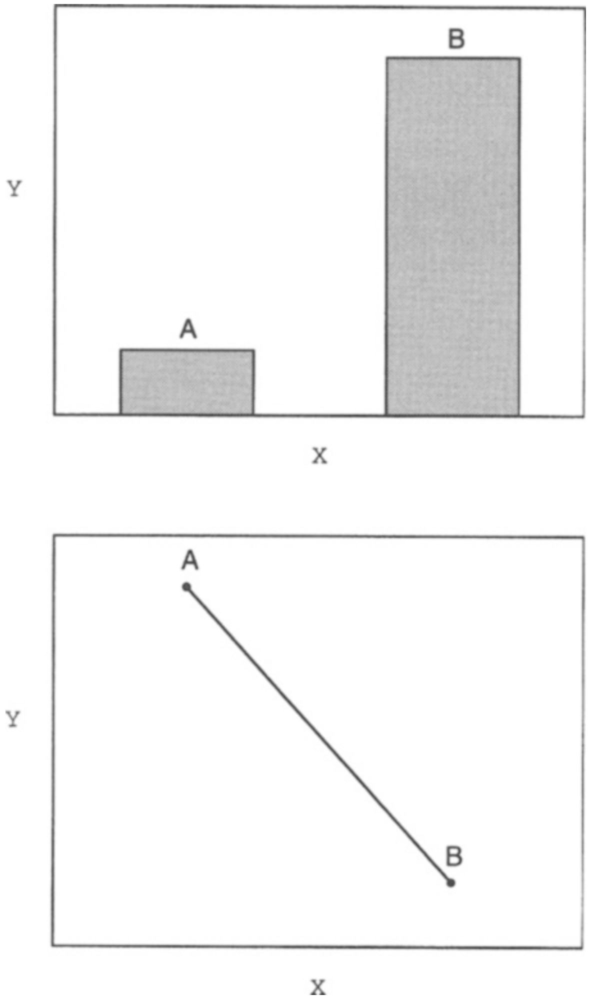

Figure 1. Examples of the bar and line graph stimuli used in Experiment 1.

This prediction of an interaction between graph type and ease of judgment has been supported by empirical results. Simcox (1984, described in Pinker, 1990) found that viewers were faster to judge the absolute values of data points from bar graphs, and faster to judge slope from line graphs. In related (as yet unpublished) work, we have found that viewers were faster to make discrete comparisons from bar graphs than from line graphs. For trend judgments, there was no difference between the two graph types. This pattern held even when the graphs contained only two data points, where the discrete comparison and the trend assessment are formally equivalent (Zacks, Levy, Tversky, & Schiano, 1996). Finally, Simkin and Hastie (1987) found that viewers were more accurate in making discrete comparisons from bar graphs than from pie graphs, whereas the opposite was true for proportion-of-the-whole judgments. Also, in a survey they found that viewers spontaneously described bar graphs as discrete comparisons and described pie graphs as proportions of the whole.

Origins of the Bar–Line Message Correspondence

This analysis suggests that people should be more likely to interpret information presented in bars in terms of discrete data points and information presented in lines in terms of relations among data points. Specifically, information presented as bar graphs should be described as *discrete comparisons* between individual data points, using terms such as *higher*, *lower*, *greater than*, and *less than*. On the other hand, information presented as lines should be described as *trends* between the data points, using terms such as *rising*, *falling*, *increasing*, and *decreasing*. In the first two experiments reported here, we examined people's spontaneous descriptions of data graphed as bars or lines.

Mirroring the predictions for comprehension of graphics are predictions for production of graphics. When asked to graphically represent information described with discrete comparisons, using terms such as *greater than*, people should produce relatively more bars than lines. When asked to graphically represent information described with trends, using terms such as *increases*, people should produce relatively more lines than bars. In Experiment 3, we examined people's constructions of graphs for representing data described discretely or continuously.

EXPERIMENT 1

In Experiment 1, we asked participants to describe simple unlabeled bar or line graphs. Because the graphs had no content, only the perceptual array could be used for interpretation. We predicted that participants would be disposed to describe the bar graphs in terms of discrete comparisons and the line graphs in terms of trends.

Method

Participants. Sixty-nine Stanford University undergraduates participated in this experiment to partially fulfill a course requirement.

Stimuli and Procedure. Simple graphs were drawn of a two-point data set. The two points were always drawn so as to be appreciably different; which point was higher was randomized across participants. The horizontal axis was labeled X, and the vertical axis was labeled Y. The data point on the left was labeled A, and the one on the right was labeled B. One aspect of the figures was manipulated: The participants saw a version of the graph drawn either as a bar graph or as a line graph. Examples of the stimuli are shown in Figure 1. Below each graph was the instruction "Please describe in a sentence what is shown in the graph above."

Two-point data sets were selected in order to control complexity. With these stimuli, a trend assessment conveys the same logical information as a discrete comparison does. For example, "Y rises from A to B" is logically equivalent to "Y is higher at A than B." In more complex data sets, discrete comparisons are possible, based on a subset of the data, which may require the processing of less information than that required for trend assessments. Similarly, trend

Table 1
Frequency of Data Characterization Responses as a Function of Graph Type

Domain	Bar	Line
Discrete comparison	28	0
Trend assessment	5	36

assessments in such figures may be possible, based on noisier estimates of the data values.

In all three experiments, the stimuli were printed on one half of an 8.5 × 11 in. sheet of paper and distributed as part of a packet of questionnaires (yielding unequal samples for the various versions).

Results

Three judges (the first author and two judges, who were naive as to the hypotheses and blind to the conditions) classified each response as either a *discrete comparison* between the two points or a *trend assessment*. They were given the following instructions:

> Classify the way the sentence characterizes the data as a comparison or a trend description. Comparisons use terms like more/less, more/fewer, higher/lower, larger/smaller, stronger/weaker; they tend to refer to discrete values. Trend descriptions use terms like function, relationship, correlation, varies, trend; they tend to refer to continuous changes in the variables. Not all the sentences will have unambiguous assignments; use your judgment.

All three judges agreed on 59 of the 69 responses; for the remaining 10 responses, the majority judgment was analyzed. Of the 69 responses, *every* line graph was described with a trend assessment, and all but five of the bar graphs were described with discrete comparisons [$\chi^2(1) = 47.9, p < .001$]. Table 1 shows this pattern.

The responses were quite variable. Most participants gave conceptual descriptions of the relationship between the data points A and B, but some gave physical characterizations of the graph and others invented fictional situations. Discrete comparisons included "A is a larger Y quantity than B," "Y is greater in a than B," and "B is bought more often than A." Trend assessments included "As X increases, Y decreases"; "A line, drawn on the XY plane, descending from A to B along the X axis"; and "As x increases in value y increases." Note that both kinds of statement convey *exactly the same* logical information ("A is a larger Y quantity than B" mutually entails "As X increases, Y decreases"). However, the conceptual content of the two kinds of description is very different.

To summarize, the participants' interpretations of content-free graphs were strongly in accord with the bar–line message correspondence. When they saw bar graphs, they described discrete contrasts in the data; when they saw line graphs, they described trends.

EXPERIMENT 2

Experiment 1 demonstrated the pure influence of graph type on conceptual interpretation. The content of a graph—specifically, the nature of the variables represented—should also affect the interpretation of the graph. If the effects of content are much larger than those of graph type, we may dismiss the latter as a "hot house" laboratory curiosity. On the other hand, if the effects of graph type on conceptual structure hold up in the face of real-world variations in content, theories of graphical perception will need to account for them. In Experiment 2, we manipulated the conceptual domain of the graph along with the graph type. The dependent variable was always continuous (height). For the independent variable, the *categorical* conceptual domain of gender was contrasted with the *continuous* domain of age. This produced situations in which the bar–line message correspondence conflicted with the content of the data. Most interesting is the case in which line graphs were used with gender as the conceptual domain. According to the bar–line message correspondence, viewers should interpret the graph as depicting a trend in the data. However, the underlying data domain was categorical, precluding the existence of a continuous trend. In this situation, how would people describe the graph?

Method

Participants. One hundred six Stanford University undergraduates participated in this experiment to partially fulfill a course requirement.

Stimuli and Procedure. The stimuli were similar to those used in Experiment 1. Two factors were manipulated: graph type (bars or lines, as in Experiment 1) and conceptual domain (discrete or continuous). Two domains were selected so that the dependent variable could be held constant while the nature of the independent variable was manipulated. In the discrete version, the two points were labeled *Female* and *Male*. In the continuous version, the points were labeled *10-year-olds* and *12-year-olds*. The vertical axis was always labeled *Height (inches)*. Examples of the stimuli are shown in Figure 2.

In the previous experiment, we noted that a minority of the participants' responses did not describe the data shown by the graph. Several described the physical appearance of the figure, and several created fictional explanations of the depicted data. To reduce the number of these types of responses, the instructions were changed slightly. Below each graph was the instruction "Please describe in a sentence the relationship shown in this graph." Questionnaires were printed and distributed as in Experiment 1.

Results and Discussion

Because there was good agreement among the judges about the graph descriptions in Experiment 1, only the first author rated the descriptions, blind to graph type.

Effects of graph type and conceptual domain on the participants' interpretations were investigated by fitting log-linear models. We tested the effect of a factor by comparing the simplest model that contained its interaction with the dependent variable (description type) with a model with that interaction removed. In each case, we estimated both Pearson's χ^2 and the likelihood ratio χ^2, and we report the more conservative of the two (which, in this case, was always Pearson's χ^2).

Both the graph type and the conceptual domain affected the participants' descriptions (see Table 2). As in Experiment 1, the participants were more likely to use a discrete comparison for a bar graph than for a line graph and more likely to make a trend assessment for a line graph than for a bar graph [$\chi^2(1) = 21.5, p < .001$].

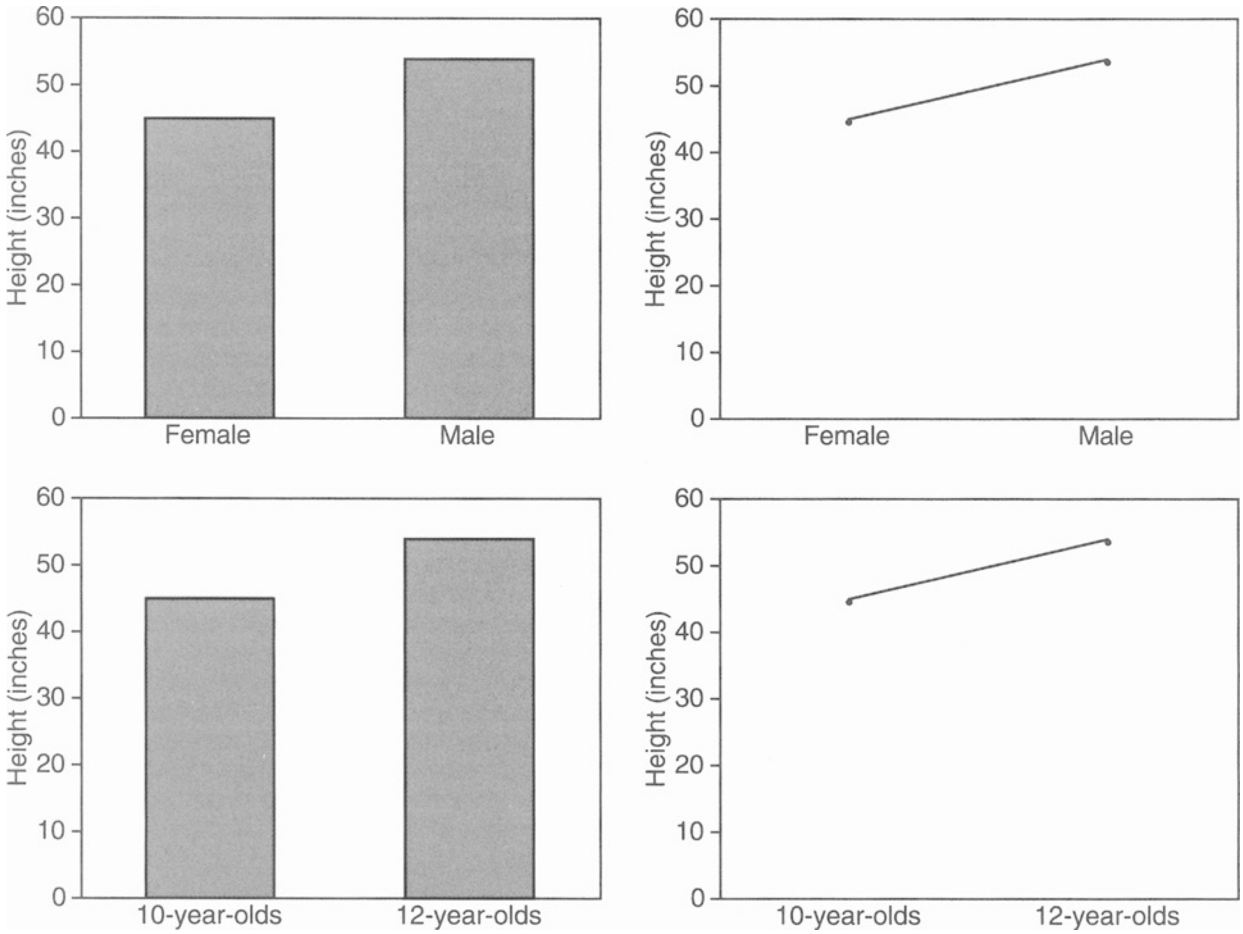

Figure 2. Examples of the bar and line graph stimuli and the continuous and categorical conceptual domains used in Experiment 2.

Also, the participants were more likely to make a discrete comparison when the conceptual domain was gender and more likely to use a trend judgment when the conceptual domain was age [$\chi^2(1) = 14.3, p < .001$]. (Because some cells had small values, we also performed an analysis collapsing over graph type and domain in turn and computed χ^2 tests of independence; it gave the same results.)

Responses in general varied less than those in the first experiment. Descriptions were usually of the depicted variables, with few physical characterizations or fictional stories. Examples of the discrete comparisons included "Male's height is higher than that of female's," "The average male is taller than the average female," and "Twelve yr olds are taller than 10 yr olds." Trend assessments included "The graph shows a positive correlation between a child's increases in age and height between the ages of 10 and 12," "Height increases with age. (from about 46 inches at 10 to 55 inches at 12)," and "The more male a person is, the taller he/she is."

The last example deserves particular comment. The fact that some participants (3 out of 25) used a trend assessment to describe a domain that was clearly categorical illustrates the power of the bar–line message correspondence. A comparison of the odds ratios for the two effects (15 for graph type, 7.0 for domain) shows that the effect of graph type was about twice that of conceptual domain. This indicates that the biasing effect of graph type is something to be reckoned with, even in more "ecologically valid" situations.

The effect of conceptual domain on qualitative descriptions agrees well with research showing that manipulating the conceptual domain can lead to quantitative distortion in the perception of graphs. For example, in one experiment, Tversky and Schiano (1989) showed that labeling a figure as a graph led to distortion of a diagonal line, whereas labeling the same figure as a map did not.

EXPERIMENT 3

The two previous experiments showed that the bar–line message correspondence systematically influenced readers' conceptual understanding of a graph. If readers were sensitive to this correspondence, would authors be so as well? Experiment 3 was designed to answer this question.

Table 2
Frequency of Data Characterization Responses as a Function of Graph Type (Bar Graph or Line Graph) and Conceptual Domain (Discrete or Continuous)

	Discrete Domain (Gender)		Continuous Domain (Age)	
Domain	Bar Graph	Line Graph	Bar Graph	Line Graph
Discrete comparison	28	22	28	9
Trend assessment	0	3	2	14

Method

Participants. Ninety-nine Stanford University undergraduates participated in this experiment to partially fulfill a course requirement.

Stimuli and Procedure. The stimuli for this experiment were essentially the inverse of those used in Experiment 2. The participants were given a description of a data pattern together with a labeled frame for a graph and asked to draw a graph. The discrete comparison descriptions were "Height for males is greater than for females" or "Height for 12-year-olds is greater than for 10-year-olds." The trend assessment descriptions were "Height increases from females to males" or "Height increases from 10-year-olds to 12-year-olds." Note that the trend assessment descriptions were constructed in order to mention the x-axis values in the same way as the discrete comparison descriptions, and therefore were not as strong as they could have been (e.g., "Height increases with age"). Questionnaires were printed and distributed as in Experiments 1 and 2.

Results and Discussion

Of the 99 forms that were returned, most of the drawings were line graphs (57) or bar graphs (32). Of the remaining 10, 6 could be described as scatter plots. Only the bar graph and line graph responses were analyzed further.

We analyzed the data in the same fashion as for Experiment 2, by fitting log-linear models to test differences in goodness of fit. Again, the presence of an empty cell in the frequency table is a problem for the χ^2 approximations. As a check, we again computed χ^2 tests of independence, which gave the same results as did the log-linear analysis reported below.

The results of Experiment 3 mirror those of the previous experiments. Given a discrete comparison description, the participants tended to draw bar graphs; given a trend assessment description, they tended to draw line graphs [$\chi^2(1) = 15.3$, $p < .001$]. Also, they were more likely to use a bar graph for the categorical conceptual domain and more likely to use a line graph for the continuous domain [$\chi^2(1) = 9.83$, $p = .002$]. The data are given in Table 3.

These results show that creators of graphs are sensitive to the bar–line message correspondence in a fashion that parallels that of readers. Also mirroring the results of Experiment 2, the effect of description type was more powerful (odds ratio = 6.6) than that of conceptual domain (odds ratio = 3.8), suggesting that the correspondence exerts a significant influence in real-world situations.

EXCLUDING EXPLICIT INSTRUCTION OF THE CORRESPONDENCE

So far, we have shown that participants describe data portrayed by bars as discrete comparisons and data portrayed by lines as trends. Similarly, they produce bars to depict described discrete comparisons and lines to depict described trends. However, since this principle is recommended in some manuals (Kosslyn, 1993), it is possible that the participants responded on the basis of explicit application of a rule. Also, the participants in Experiment 1 could have responded on the basis of explicit knowledge of another correspondence: the use of bar graphs to depict categorical independent variables and line graphs to depict continuous independent variables. We will call this the *bar–line data correspondence*, because it establishes a mapping between the graph type and the data type. It can be distinguished from the bar–line message correspondence described earlier: the use of bar graphs to depict comparisons among discrete data points and line graphs to depict trends. The bar–line message correspondence relates the intended message of the graph's author to the graph type, independently of the data type. This principle is also recommended in style manuals (Kosslyn, 1993), including the *Publication Manual of the American Psychological Association* (Amercan Psychological Association, 1994).

To evaluate the influence of explicit knowledge or rule following on participants' judgments, we queried the par-

Table 3
Frequency of Graph Type Drawn as a Function of Description Type (Discrete Comparison or Trend Assessment) and Conceptual Domain (Discrete or Continuous)

	Discrete Domain (Gender)		Continuous Domain (Age)	
Graph Type	Discrete Comparison	Trend Assessment	Discrete Comparison	Trend Assessment
Bar	14	7	11	0
Line	6	13	14	24

ticipants in Experiments 1 and 2 about their experience with formal statistics. Of the 69 participants in Experiment 1, 9 indicated that they had taken or were currently taking one statistics class (none reported more). Of the 106 participants in Experiment 2, 17 reported that they had taken or were currently taking a college-level statistics class. Of these, 1 had taken more than one. These low rates of experience with formal instruction in statistics suggest that it is unlikely that participants had been instructed in rules for either the bar–line message correspondence or the bar–line data correspondence.

Despite this lack of classroom experience in statistics, it is possible that participants were instructed in relevant rules for graphing in some other college or high-school class. To evaluate the explicit knowledge of these rules in the population under study, we asked three questions of a sample of undergraduates from Stanford University and other U.S. universities and a sample of current and recent Stanford University graduate students in psychology. Participants were given a questionnaire with the following three questions:

1. Are you aware of any convention regarding when one should use a bar graph and when one should use a line graph?
2. If you answered "yes," please describe the rule and where you learned it, if you remember.
3. If you answered "no," do you have any suggestions as to what would make a good rule for choosing between a bar graph and a line graph?

Responses were classified as *aware* if they answered "yes" to the first question. Responses to the second or third question (depending on the answer to the first) were classified as *message* responses if they described a relationship between the intended message of the graph and the graph type and as *data* responses if they described a relationship between the horizontal-axis data type and the graph type. Of the 32 undergraduates, 9 reported that they were aware of any such convention. Of those, 4 gave *data* responses, and 3 gave *message* responses. (The remaining two responses could not be classified as either category.) Of the 14 graduate students, 8 reported that they were aware of a convention governing bar and line graphs. Of those responses, six could be classified as *data* responses, one as a *message* response, and one as neither.

To summarize, few participants in Experiments 1 and 2 reported having taken a statistics class. Of the undergraduates surveyed, few reported knowledge of any convention governing the use of bar and line graphs, and even fewer reported awareness of a convention relating the use of bar or line graphs to the intended message. A higher proportion of graduate students reported awareness of a convention for using the two graph types, but most described a rule relating graph type to data type rather than to conceptual message. It is therefore unlikely that the participants in the experiments reported here responded on the basis of an explicit rule for the bar–line message correspondence. We should note that in Experiments 2 and 3, to the extent that the participants responded on the basis of an explicit rule for the bar–line data correspondence, the results *underestimate* the relative influence of the bar–line message correspondence (by overestimating the effect of the data domain manipulation).

GENERAL DISCUSSION

In two experiments, participants wrote descriptions of relations portrayed in bar or line graphs. There was a strong tendency to describe data portrayed as bars discretely (e.g., "A is higher than B") and to describe data portrayed as lines in terms of trends (e.g., "X increases from A to B"). In Experiment 2, we also examined effects of categorical or continuous variables in the data. In Experiment 3, participants were given the reverse task: Given relations described by a discrete comparison or a trend assessment, construct a graphic display. There was a strong tendency to portray discrete comparison descriptions as bars and trend assessment descriptions as lines. In Experiments 2 and 3, the effects of graph type or description type were larger than the effects of the underlying data domain. Participants were largely unaware of rules relating graph types to conceptual messages, making it unlikely that these choices reflected knowledge of explicit rules. Thus, people's comprehension and production of graphs conform to the principles of cognitive naturalness and information-processing ease discussed in the introduction. In particular, they follow the bar–line message correspondence: the use of bar graphs to depict comparisons among discrete data points and the use of line graphs to depict trend.

The data reported here establish how interpretations and constructions of simple graphs follow the bar–line message correspondence. This principle surely does not govern all choices or interpretations of graphic displays. Factors such as the complexity of the data set and the rendering characteristics of the graphs (such as bar width, color, and the addition of 3-D shading) are likely to modulate uses and interpretations

Where do such patterns in graphical interpretation and production come from? It seems likely that they originate in biases in our perceptual and cognitive abilities. However, these perceptual–cognitive biases give rise to only small effects in ease of information extraction (Zacks et al., 1996) and small differences in cognitive naturalness (Tversky et al., 1991). How do small effects of cognitive naturalness and information extraction yield large effects in graph interpretation and production?

One possible explanation for the power of the bar–line message correspondence is that it reflects the development of a communicative convention. Conventions may originate in a small initial bias that breaks a symmetry (e.g., the perceptual–cognitive biases described earlier). In a community of producers and recipients of graphical communications, this bias would initially make graphics more readily understood and the information in them more easily extracted, based solely on considerations of information processing and cognitive naturalness. This would likely promote authors' systematic use of bar and line graphs. Once such a bias is exploited by authors, viewers over time may come to rely on that regularity. This further enhances the bias and thereby its use, exerting positive feedback for the convention. Thus, small perceptual–cognitive biases are parlayed into large effects as a result of positive feedback from communicative interactions. This process leads to the development of a graphical convention. It can be likened to the way in which speech conventions develop in a community of users (Clark, 1996).

Cognitive scientists interested in graphic perception have traditionally looked at perceptual–cognitive processes from the point of view of the solitary observer. A complete understanding requires expanding the picture to include dynamic interactions in communication.

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NOTE

1. Graphical perception, including the comprehension of trends and discrete comparisons from line and bar graphs, has also been modeled quantitatively by Lohse (1993). However, specific predictions about the interaction of graph type (bar vs. line) and task were not reported.

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