Bars and Lines: A Study of Graphic Communication

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Abstract

Interpretations of graphic displays of information seem to be rooted in principles of cognitive naturalness and information processing rather than arbitrary correspondences. Both of these considerations predict that people should more readily associate bars with discrete information because bars are discrete entities and facilitate point estimates. Similarly, people should more readily associate lines with trends because lines connect discrete entities and directly represent slope. In two experiments, viewers tended to describe bar graphs in terms of discrete comparisons between individual data points, while they tended to describe line graphs in terms of continuous trends. In a third experiment, participants sketched graphic displays to illustrate verbal descriptions of data; they tended to use bar graphs to convey discrete comparisons, and line graphs to convey trends. The strength of the bar/line convention seems to depend on the communicative situation as well as the perceptual and conceptual properties of the graphic displays.

Introduction

Graphs are a pervasive species of cognitive artifact, used both to reason about data and to communicate them. Given a particular data set, there are a large number of ways it could be portrayed, and people develop conventions that govern what techniques are used in a given situation. One such convention is the use of bar graphs to depict comparisons among discrete data points and line graphs to depict trends. This convention is reflected in instructional books (Kosslyn, 1993), publication manuals (American Psychological Association, 1994), and in the frustrated complaints of editors when it is violated. It does not seem to be arbitrary. On the one hand, it fits with the way people use space to convey meaning. On the other hand, it fits with the ease with which people extract information from graphics.

In the sections that follow, we will describe how the bar-line convention could originate from biases in the perceptual and cognitive abilities of graph viewers. We will then present data documenting how the convention functions both for viewers and authors of graphs. Based on the strength of the effect, and on the relationship of authors' choices to viewers' behavior, we conclude that the convention can't be fully understood just in terms of the information-processing properties of graph viewers, but requires thinking about 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). This may be the case for bars and lines as well. 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 they perceive as representing levels of an underlying dimension but do not line up dots they do not perceive as related dimensionally (Tversky, Kugelmass & Winter, 1991). In selecting what graphic displays they would use for conveying various sorts of information, adults prefer to use bars for conveying discrete information 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. In bar graphs, each value is represented as a separate bar, suggesting separate entities or categories, whereas in line graphs, values are connected by a single line, suggesting that all the values belong to the same entity.

Information-processing Models Of Graphical Perception

Pinker (1990) has developed the most detailed information-processing theory of graph comprehension. In Pinker's model, a graph reader first builds up a visual description of the visual display, similar to Marr's (1982) 2 1/2 D sketch. This representation is constrained by several factors, including Gestalt laws of grouping and prior experience with other graphs. From the visual description, a graph reader constructs conceptual messages, which are propositions about variables depicted in the graph. The reader can also construct conceptual questions, which are essentially conceptual messages with missing values. High-level inferential processes are available to operate on conceptual messages.

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" (1990, p. 11). Based on the theory, Pinker 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] The Gestalt principles again support this prediction. Absolute values are easier to discern when the values are presented separately, as in bars, whereas trends are easier to discern when values are connected, as in lines.

The prediction of an interaction between graph type (bar vs. line) and ease of making discrete comparisons or trend assessments is also supported by empirical results. Simcox (1984, described in Pinker, 1990) found that viewers were faster to make judgments about the absolute value of data points with bar graphs than with line graphs, but faster to make judgments of slope with line graphs than with bar graphs. This pattern held both for a sorting task and a classification task. In related (as yet unpublished) work, we 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. Interestingly, this pattern held even when the graphs contained only two data points. In this case, the discrete comparison and the trend assessment are formally equivalent (Zacks, Levy, Tversky & Schiano, 1996). Finally, Simkin and Hastie (1987) compared bar graphs (of a type slightly different from that used in our experiments) with pie graphs for discrete comparison judgments and proportion-of-the-whole judgments. They found viewers were more accurate making discrete comparisons with the bar graphs than the pie graphs, while the opposite was true for proportion-of-the-whole judgments. Also, they reported that in a survey, viewers tended to spontaneously describe bar graphs in terms of discrete comparisons, and to describe pie graphs in terms of proportions of the whole.

Origins of the Bar-Line Convention

Together, the theory and results described above suggest that people should be more likely to interpret information presented in bars as deriving from discrete variables and information presented in lines as deriving from continuous underlying variables. This should be evident in the way they describe the depicted relations. Information presented as bar graphs should be described categorically, in terms of 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 continuous trends between the data points, using terms like "rising," "falling," "increasing," and "decreasing." The first two experiments examine people's spontaneous descriptions of data graphed as bars or lines.

Mirroring the predictions for comprehension of graphics are the predictions for production of graphics. When asked to graphically represent information described categorically, using terms like "greater than," people should produce relatively more bars than lines. When asked to graphically represent information described continuously, using terms like "increases," people should produce relatively more lines than bars. The last experiment examines people's constructions of graphs for representing data described discretely or continuously.

Experiment 1

In the first experiment, we presented participants with simple bar or line graphs and asked them to describe what they saw. We predicted that viewers would be more likely to describe the bar graphs in terms of discrete comparisons between the individual data points. On the other hand, we predicted they would be more likely to describe the line graphs in terms of continuous trends.

Method

Participants. 69 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 counterbalanced across viewers. 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 labeled "B." One critical factor was manipulated: viewers either saw a version of the graph drawn 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:". The graph and instructions took up half a page; the other half was printed with another unrelated question about graphs. The graphs were printed on 8.5" x 11" paper and distributed as part of a packet of questionnaires. (A note: though equal numbers of each version of the graph were distributed, not all the questionnaire packets were fully completed, so the numbers of participants viewing each graph version was not equal. The same was true for the two studies described below.)

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[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.

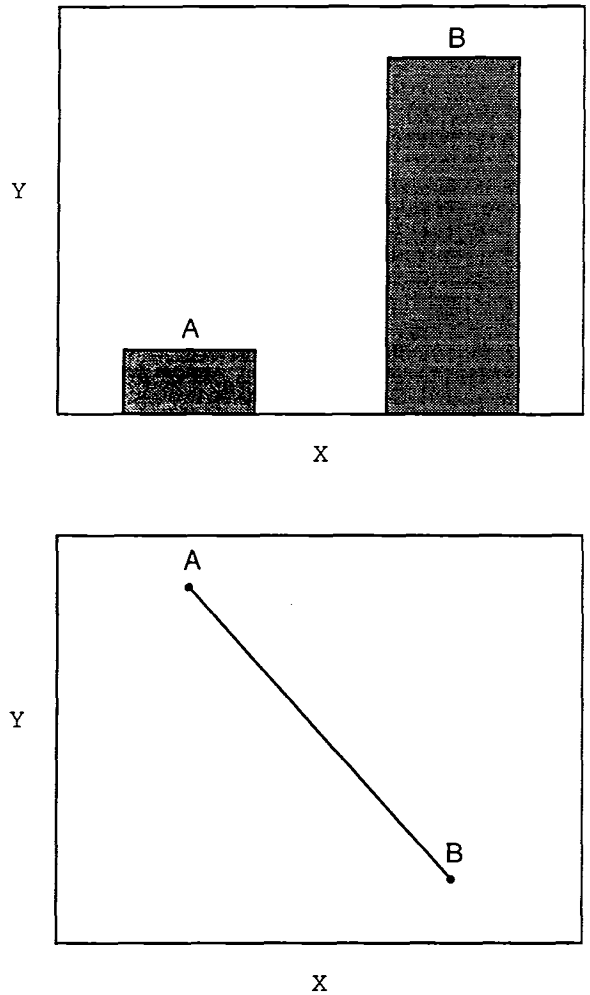

Figure 1: Examples of the bar and line graph stimuli used in Experiment 1.

Results

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

"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; the 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 those 59 responses, every bar graph was described with a discrete comparison and every line graph was describe with a trend assessment, $\chi^2(1) = 54.9$, $p < .001$. Table 1 shows this pattern.

	Bar graph	Line graph
Discrete comparison	24	0
Trend assessment	0	35

Table 1: Frequency of data characterization responses as a function of graph type.

The particular content of the responses was quite variable. Most respondents provided conceptual descriptions of the relationship between the data point A and B, but some gave physical characterizations of the graph, and others invented fictional situations to explain the data. The following are three typical "discrete comparison" responses, and three typical "trend assessment" responses:

Discrete comparisons:

"Y is greater in a than B"
"A is a larger Y quantity than B"
"B is bought more often than A"

Trend assessments:

"A line, drawn on the XY plane, descending from A to B along the X axis"
"As x increases in value y increases"
"As X increases, Y decreases"

To summarize, the deployment of the bar-line convention had an unambiguous affect on the disposition of the readers to respond. 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 existence of a bar-line convention effect on conceptual structure. Is this effect a "hot house" laboratory phenomenon, or does it reflect processes that have real impact on our interactions in the world? One way to get at this question is to add a salient source of real-world variation in conceptual structure and check to see that the bar-line convention effect holds up. Experiment 2 did this by manipulating the conceptual domain of the graph along with the graph type. The dependent variable was always continuous (height). For the independent variable, the discrete conceptual domain of gender was contrasted with the continuous domain of age. This produced situations in which the bar-line convention conflicted with the content of the data. Most interesting is the case where line graphs were used with gender as the conceptual domain. Here the convention implies that a continuous trend is being depicted, but the domain is clearly discrete. In this situation, how will people describe the graph?

Method

Participants. 106 Stanford University undergraduates participated in this experiment to partially fulfill a course requirement.

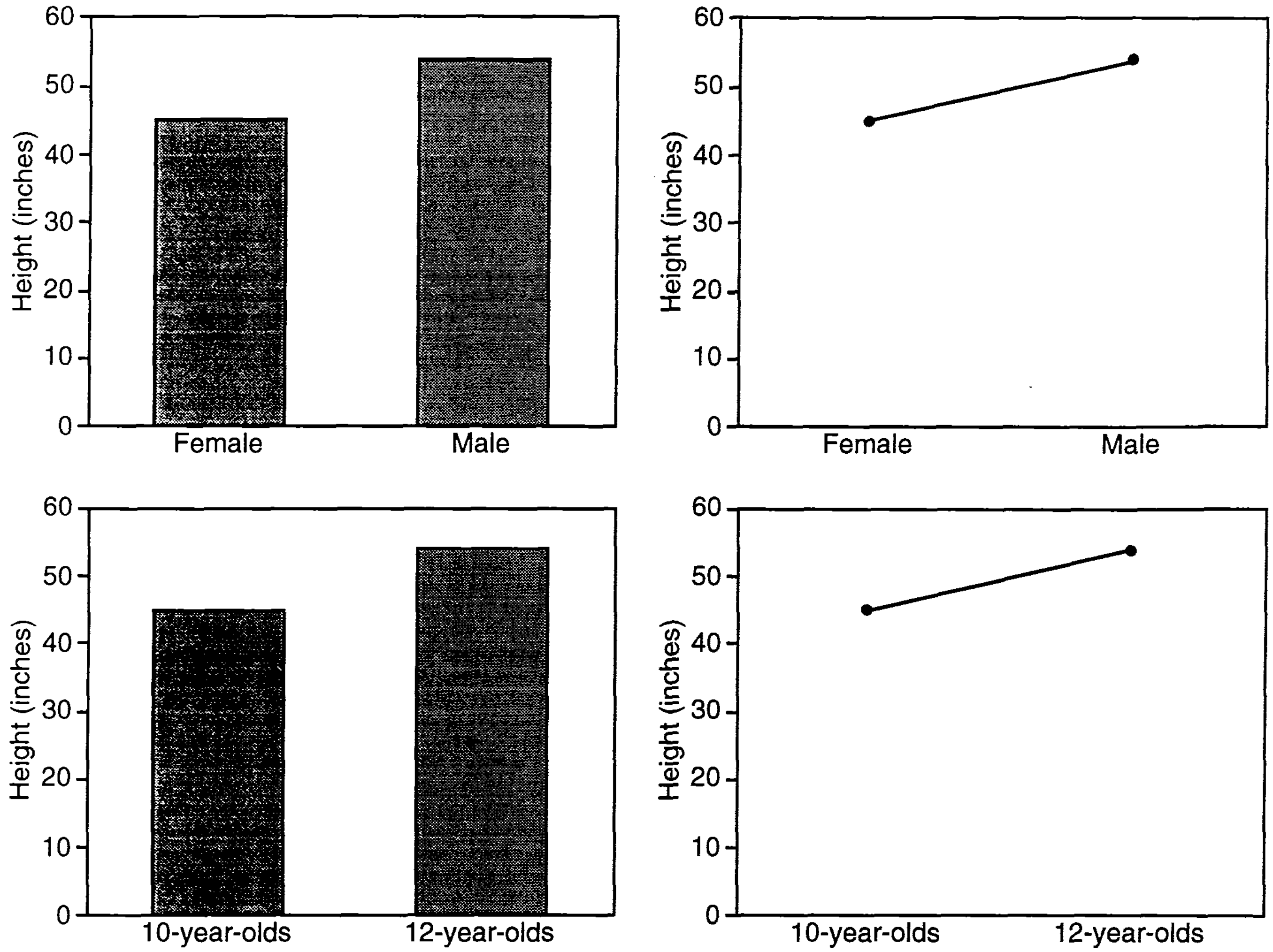

Figure 2: Examples of the bar and line graph stimuli, and the continuous and discrete conceptual domains used in Experiment 2.

Stimuli and procedure. The stimuli were quite similar to those used in Experiment 1. Simple graphs were drawn of a two-point data set. The two points were always drawn so as to be appreciably different; the second point was always higher than the first.

In this experiment, two factors were manipulated. As in Experiment 1, viewers either saw a version of the graph drawn as a bar graph or as a line graph. Also, the conceptual domain of the data was manipulated by varying the labeling of the points and axes. Two domains were selected such that the dependent variable could be held constant while the nature of the independent variable was manipulated. In one version (the "gender" domain), the two points were labeled "Female" and "Male." In the other version, (the "age" domain) the points were labeled "10-year-olds" and "12-year-olds." The vertical axis was always labeled "Height (inches)." In the first version, the two labels identified (more-or-less) discrete categories; thus the labels denoted a discrete conceptual domain. For the second version the labels denoted a continuous variable, age, and therefore a continuous conceptual domain. To summarize, a given graph stimulus was either associated with a discrete or continuous conceptual domain, and either was drawn as a bar graph or line graph. Examples of the stimuli are shown in Figure 2.

In the previous experiment, it had been noted that a minority of the 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:" (rather than simply asking for a description of what is shown). The graph and instructions took up half a page; the other half was printed with another unrelated question about graphs. The graphs were printed on 8.5" x 11" paper and distributed as part of a packet of questionnaires.

Results

Because there was good agreement among the judges about the graph descriptions in Experiment 1, only the first author

	Gender (discrete domain)		Age (continuous domain)	
	Bar graph	Line graph	Bar graph	Line graph
Discrete comparison	28	22	28	9
Trend assessment	0	3	2	14

Table 2: Frequency of data characterization responses as a function of graph type (bar graph or line graph) and conceptual domain (gender or age).

rated the descriptions. During rating, he was blind to the type of graph presented.

Effects of graph type and conceptual domain on viewers' propensity to make a discrete comparison or a continuous trend assessment 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 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 exerted effects on viewers' descriptions of the graphs (see Table 2). As in Experiment 1, 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 a bar graph, $\chi^2(1) = 21.5$, $p < .001$. Also, 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, $\chi^2(1) = 14.3$, $p < .001$. (We should be somewhat skeptical of the accuracy of the χ^2 approximation, given that one of the cells in Table 2 contains a zero. As a check, we performed an analysis in which we collapsed over graph type and domain in turn and computed χ^2 tests of independence; it gave the same results.)

Responses were in general less variable 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 and trend assessments follow.

Discrete comparisons:

"Male's height is higher than that of female's"

"The average male is taller than the average female."

"Twelve yr. olds are taller than 10 yr olds."

Trend assessments:

"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)"

"The more male a person is, the taller he/she is"

The last example deserves particular comment. The fact that some participants were willing to use a continuous trend assessment to describe a domain that was clearly discrete illustrates the power of the bar-line convention. (3 of the 25 participants who saw that stimulus gave such a response.) Comparing the odds ratios for the two effects (15.4 for graph type, 7.2 for domain) shows that the effect of graph type was about twice as big as 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. In one experiment, Tversky and Schiano (1989) showed that labeling a figure as a graph led to distortion of a diagonal line, while labeling the same figure as a map did not.

Experiment 3

The two previous experiments showed that the bar-line convention systematically influenced readers' conceptual understanding of a graph. If readers are sensitive to this convention, are authors as well? Experiment 3 was designed to answer this question.

Method

Participants. 99 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 the previous experiment. Participants were given a description of a data pattern together with a frame for a graph, and asked to draw a graph. The conceptual domain and the labeling of the frames was just as it had been in Experiment 2. In one version (the "gender" domain), the two points were labeled "Female" and "Male." In the other version, (the "age" domain) the points were labeled "10-year-olds" and "12-year-olds." The vertical axis was always labeled "Height (inches)". The descriptions were either discrete or continuous. The discrete descriptions were:

	Gender (discrete domain)		Age (continuous domain)	
	Discrete description	Trend description	Discrete description	Trend description
Bar graph	14	7	11	0
Line graph	6	13	14	24

Table 3: Frequency of graph type drawn as a function of description type and conceptual domain.

"In the frame above, draw a graph that depicts the following relationship:
Height for males is greater than for females."
or,
"Height for 12-year-olds is greater than for 10-year-olds."
The continuous descriptions were:
"In the frame above, draw a graph that depicts the following relationship:
Height increases from females to males."
or,
"Height increases from 10-year-olds to 12-year-olds."
The graph and instructions took up half a page; the other half was printed with another unrelated question about graphs. The graphs were printed on 8.5" x 11" paper and distributed as part of a packet of questionnaires.

Results

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 problematic for the χ^2 approximations. As a check, we again computed χ^2 tests of independence, which gave the same results as the log-linear analysis reported below.

The results of Experiment 3 mirror those of the previous experiments. Given a discrete description, participants tended to draw bar graphs; given a continuous 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 discrete 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 convention 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 = 6.61) than that of domain (odds ratio = 3.82), suggesting that the convention exerts a significant influence in real-world situations.

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, for example, "A is higher than B," and to describe data portrayed as lines in terms of trends, for example, "X increases from A to B." The second experiment also examined effects of discrete or continuous variables in the data. The influence of graphic display was far greater than that of the underlying variable. In a third experiment, participants were given the reverse task. Given relations described discretely or continuously, they were asked to construct graphic displays. There was a strong tendency to portray discrete descriptions as bars and continuous descriptions as lines.

Thus, people's comprehension and production of graphs conform to the principles of cognitive naturalness and information processing ease discussed in the introduction. They also correspond to graphic convention. Where do graphic conventions like the bar-line convention come from? It seems likely that they originate in these same perceptual and cognitive propensities. However, it seems unlikely that the perceptual-cognitive biases alone could give rise to the striking effects observed here. The differences in ease of information extraction between bar and line graphs are small (Zacks et al., 1996) as are the effects of cognitive naturalness (Tversky et al., 1991).

We believe that small perceptual-cognitive biases are parlayed into large effects due to positive feedback exerted by communicative convention. Conforming to the biases would initially make graphic communications more readily understood and the information in them more easily extracted. Once a disposition to privilege a given relationship between graphic displays and conceptual messages is exploited by authors, viewers can rely on that regularity. This further enhances the disposition and thereby its use. This process can be likened to the way speech conventions develop in a community of users (Clark, 1996).

While the origins of the bar-line convention can be traced to cognitive naturalness and information processing ease, a fuller understanding emerges when we consider the larger situation in which authors and viewers use graphs to communicate. Cognitive scientists interested in graphic perception have traditionally looked at perceptual-cognitive processes form the point of view of the solitary observer. A complete account requires expanding the picture to include processes of communication.

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