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Bias Due to Visual Illusion in the Graphical Presentation of Information

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by

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T.S. Amer, Ph.D.

I. INTRODUCTION

Graphical displays of information are among the most common decision aids. Appropriately prepared graphs can be useful to decision makers when displaying trends or relationships in data. Several preparation guidelines have been suggested over the years to guide the preparation of graphical displays of quantitative information. Recent research has demonstrated that graphs violating these guidelines may bias decision-making and alter decision choice (Arunachalam, Pei, and Steinbart forthcoming).

This paper adds to the body of literature on graphical information presentation by demonstrating that even a graph that meets all of the preparation guidelines examined by Arunachalam et al. can still result in biased information extraction due to visual illusion. Specifically, decision makers can fall prey to the so-called "Poggendorff illusion" (Poulton 1985; Gillan et al. 1998; Wickens and Hollands 2000) and either systematically underestimate or systematically overestimate the values displayed on a cost-volume-profit graph. This research also examines if adding another feature to line graphs – horizontal gridlines – moderates the bias and reduces the variance in the values extracted from line graphs by decision makers.

This paper is organized as follows: the next section discusses prior literature and presents background information, providing the context within which to place the current study. The third section sets forth the research hypotheses that were examined. The fourth section describes the experimental methodology and procedure used to test the hypotheses. The fifth section discusses the results and the statistical tests carried out, and the final section offers a general discussion and conclusions.

II. BACKGROUND

Much research over the past several years has examined the effect of alternative forms of information presentation on decision-making. Commonly referred to as the "tables versus graphs" literature, a number of studies have reported varying results (see Jarvenpaa and Dickson (1988), Amer (1991), Vessey (1991) and Frownfelter-Lohrke (1998) for summaries and reviews of this literature). An outcome of this body of research was the development of a theoretic model, based upon information processing theory, to explain under what circumstances a graphical representation outperforms a tabular representaton (Vessey 1991, 1994). Vessey's theory of cognitive fit views problem solving as an outcome of the relationship between the problem representation and the problem-solving task. It articulates that decision-making performance on a task will be enhanced when there is a cognitive fit (i.e., match) between the information emphasized in the representation and that required by the decision task.

Application of the theory of cognitive fit indicates that properly prepared graphical representations are useful for displaying trends in data or relationships in data because the visual image of a graph matches the underlying relationships between the variables displayed in the graph (DeSanctis and Jarvenpaa 1989; Vessey and Galletta 1991; Umanath and Vessey 1994).

However, improperly prepared graphs may bias decision-making and alter the choices of decision makers (Arunachalam, Pei, and Steinbart forthcoming). A number of preparation guidelines are articulated in the literature to guide the proper format and construction of graphs (Bertin 1983; Gillan et al. 1998; Jarvenpaa & Dickson 1988; Kosslyn 1989; Tufte 1983, 1997; Wainer 1997; Wickens and Hollands 2000). As pointed out by Arunachalam, Pei, and Steinbart (forthcoming) graphs are often designed not only to support decision making, but also to persuade or convince the viewer. As a result, Arunachalam et al. note that preparers often violate one or more of the graph preparation guidelines in order to create a more persuasive presentation to direct the decision maker's attention to some particular feature in the data set.

Tractinsky and Meyer (1999) found that preparers change the characteristics of bar graphs based upon the impression they wish to make on readers. Additionally, these authors note that participants in their experiment were more likely to violate the principles of graph design when the data itself reflected undesirably on the presenter. Research has also found that annual reports frequently contain graphs that are not designed in a consistent fashion with suggested guidelines (Beattie and Jones 1992; Johnson, Rice and Roemmich 1980; Courtis 1997; Steinbart 1989). For example, Beattie & Jones (1992) examined the annual reports of companies in the UK and found non-compliance with graph preparation guidelines. They also identified significant measurement distortion having the effect of portraying the company's performance more favorably. Likewise, Steinbart (1989) reports that companies that have experienced a decline in net income from a prior year are more likely to include a graph in their annual report that violates one or more suggested design guidelines than are companies that experienced an increase in earnings.

Graph Preparation Guidelines

Six guidelines are commonly cited to direct the proper presentation of quantitative information in graphical form (Arunachalam, Pei, and Steinbart forthcoming). Tufte (1983, 77) presents these six rules:

1. The magnitude of change depicted graphically should be directly proportional to the numerical change in the data.
2. Graphs should be clearly labeled to avoid any ambiguity.
3. Variation in design should mirror numerical change in the data.
4. Deflated and standardized units of monetary measurement are nearly always better than nominal units when graphing time series data.
5. Limit the number of dimensions used to depict change to the number of dimensions in the data.
6. Provide enough context to accurately interpret the data.

Arunachalam, Pei, and Steinbart (forthcoming) conducted a series of experiments to examine how deviations from these guidelines affect the choices of decision makers. Their results show that improperly designed graphs can alter subject choices.

Other research in human factors psychology suggests that even a graph that meets all of the preparation guidelines noted above may still result in biased information extraction due to visual illusion. Specifically, decision makers can fall prey to the so-called "Poggendorff illusion" (Poulton 1985; Gillan et al. 1998; Wickens and Hollands 2000) and either systematically underestimate or systematically overestimate the values displayed on a graph relative to their true values. A few studies in psychology report finding this bias in a context-neutral decision setting (Poulton 1985) but none has examined the illusion in contextually rich decision settings. In addition, and as discussed below, limited preparation guidelines are offered by psychologists to minimize the bias found in their results (Gillan et al. 1998; Wickens and Hollands 2000).

This research addresses the Poggendorff illusion and associated bias in a business and accounting decision-making context and examines the effect of adding horizontal gridlines to a graph to overcome the bias. Accordingly, the results reported in this paper make a significant contribution to the literature. First, the effects of the Poggendorff illusion are examined in a business and accounting decision-making context expanding the external validity of the findings. In prior studies by human factors psychologists the graphs that were prepared and presented contained no contextual background and the subjects often provided their responses from a "very first reading" (Poulton 1985) of the information presented on the graphs. In this study, the subjects were familiar with the decision-making context and had both studied and prepared graphs very similar to those used in the study prior to the administration of the experiment.

In addition, the results of this study illustrate the importance of considering the effects of visual illusion in the development of guidelines for constructing information displays. If a bias that results from visual illusion can be overcome by the addition of horizontal gridlines to the graph, then the guidelines for graph preparation should be modified. Human factors researchers have not explored whether the addition of horizontal gridlines to a graph can overcome the bias that results from the Poggendorff illusion.

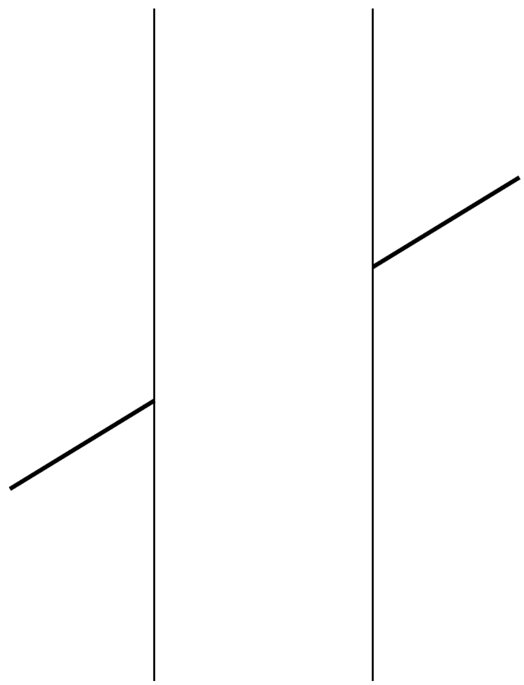
III. RESEARCH HYPOTHESES

The Poggendorff Illusion

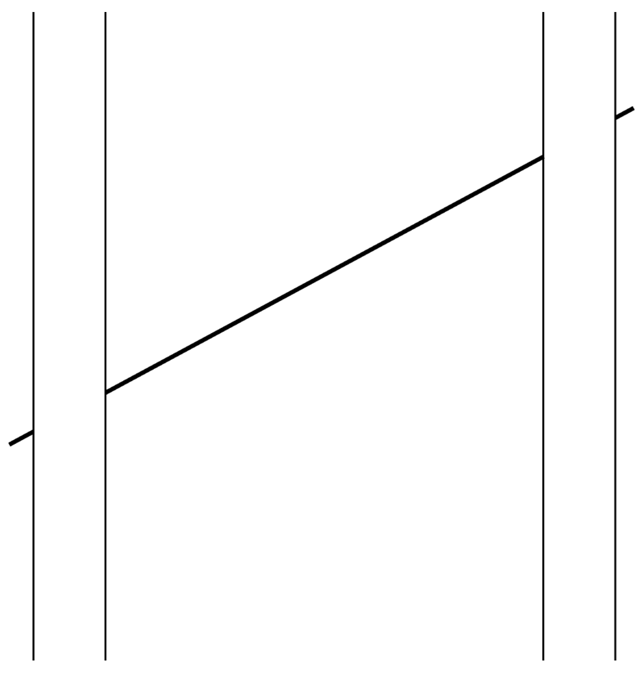
Visual illusions can occur in both two- and three-dimensional scenes and illustrations (Gibson 1950; Gregory 1963; Poulton 1985; Wickens and Holland 2000). One classic two-dimensional visual illusion is the Poggendorff figure. Figure 1.a. illustrates the traditional Poggendorff figure and Figure 1.b. illustrates an "outside-in" version of the Poggendorff figure (Poulton 1985). In both cases, the upward sloping line appears to be flatter or more horizontal then it actually is. The left and right portions of the upward sloping line in Figure 1.a. are actually on the same line with the same slope. Likewise in Figure 1.b., the small left and right portions are part of the larger upward sloping line in the center of the figure, again with the same slope. As noted by Poulton (1985), the illusion in Figures 1.a. and 1.b. also exists, to a smaller degree, even if there are fewer vertical or even ***no*** vertical lines in the two figures.

Figure 1. Poggendorff Illusions

1.a. Traditional Poggendorff Illusion



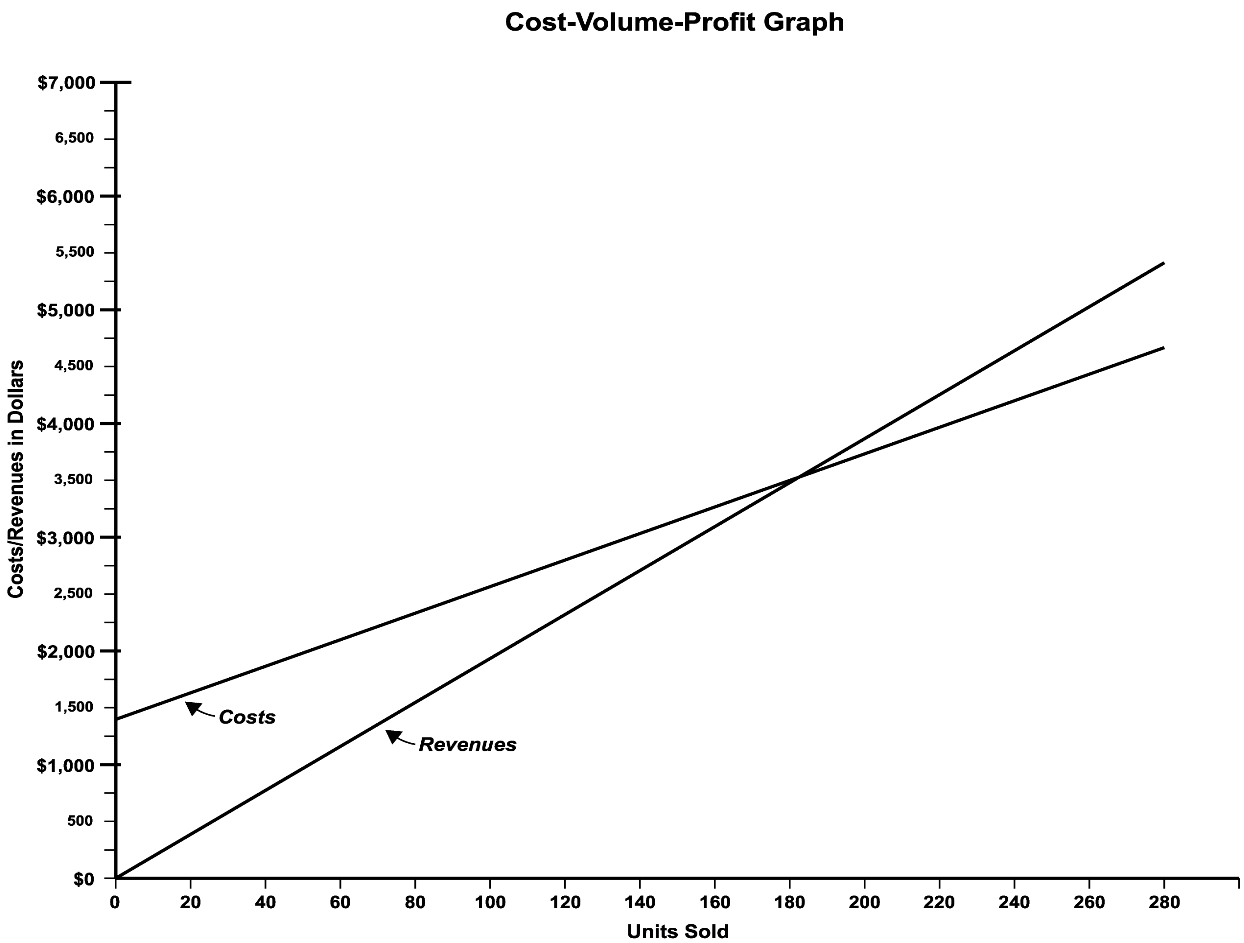
1.b. "Outside-In" Poggendorff Illusion



Implications for Information Display

The Poggendorff illusion would seem to have an obvious implication for quantitative data presented in two-dimensional line graphs. Consider the C-V-P graph presented in Figure 2 (from this point on, the C-V-P graph of Figure 2 will be referred to simply as "C-V-P Graph 1"). A traditional C-V-P graph presents the relationships between an organization's revenues, costs, and unit sales. This line graph plots the total revenues and total costs of an organization in two-dimensions. Total revenues and total costs are represented on the y-axis, the ordinate, and the number of units sold is represented on the x-axis, the abscissa. The point at which the lines cross, where total revenues equal total costs, is the break-even point. The difference between the lines at any point above the break-even point on the x-axis is, of course, the profit at a given level of sales activity. The difference between the lines at any point below the break-even point is the loss at a given level of sales activity. Accordingly, the C-V-P graph provides a visual representation of an organization's profitability at various levels of operating sales. That is, it displays the relationship between the total revenues and total costs at a given level of sales.

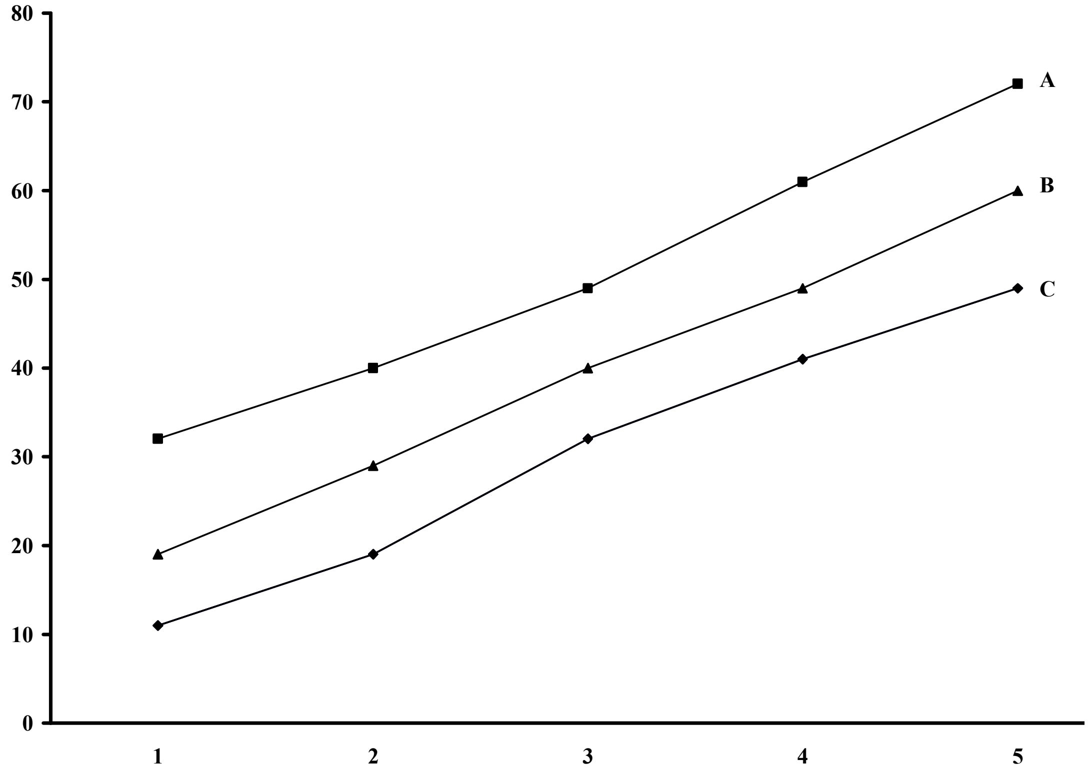
Figure 2. C-V-P Graph 1 – Two Calibrated Scales



Now compare the Poggendorff illusion of Figure 1.b. with the C-V-P Graph 1 in Figure 2. The upward sloping line in Figure 1.b. corresponds to either the total revenue line or total cost line in C-V-P Graph 1 of Figure 2. The vertical lines on the left side of Figure 1.b. correspond to the y-axis (the ordinate) of C-V-P Graph 1 of Figure 2. If the illusion holds, both the total revenue line and total cost line will be seen to be more horizontal than they are, and decision makers will perceive the corresponding dollar values referenced from the left axis of the graph to be too low. This effect will be greater as one moves farther to the right on the function plotted on the graph. Such was a finding of Poulton (1985) in a contextually neutral setting, where he examined the values decision makers extracted from the end points (the far right end of the functions) of graphs displaying hypothetical data.

A second finding of Poulton involved the plotting of multiple near-parallel functions (multiple sloping lines) on the same graph as, for example, shown in Figure 3. Poulton found that the functions plotted lowest on the graph (e.g., function C in Figure 3) were perceived to be the most horizontal ("flattest") and decision makers underestimated the values from these functions more than others. This finding was attributed to the "interference" that existed between the multiple functions plotted on the graph.

Figure 3. Multiple Near-Parallel Functions Plotted on the Same Graph
Similar to Poulton (1985)

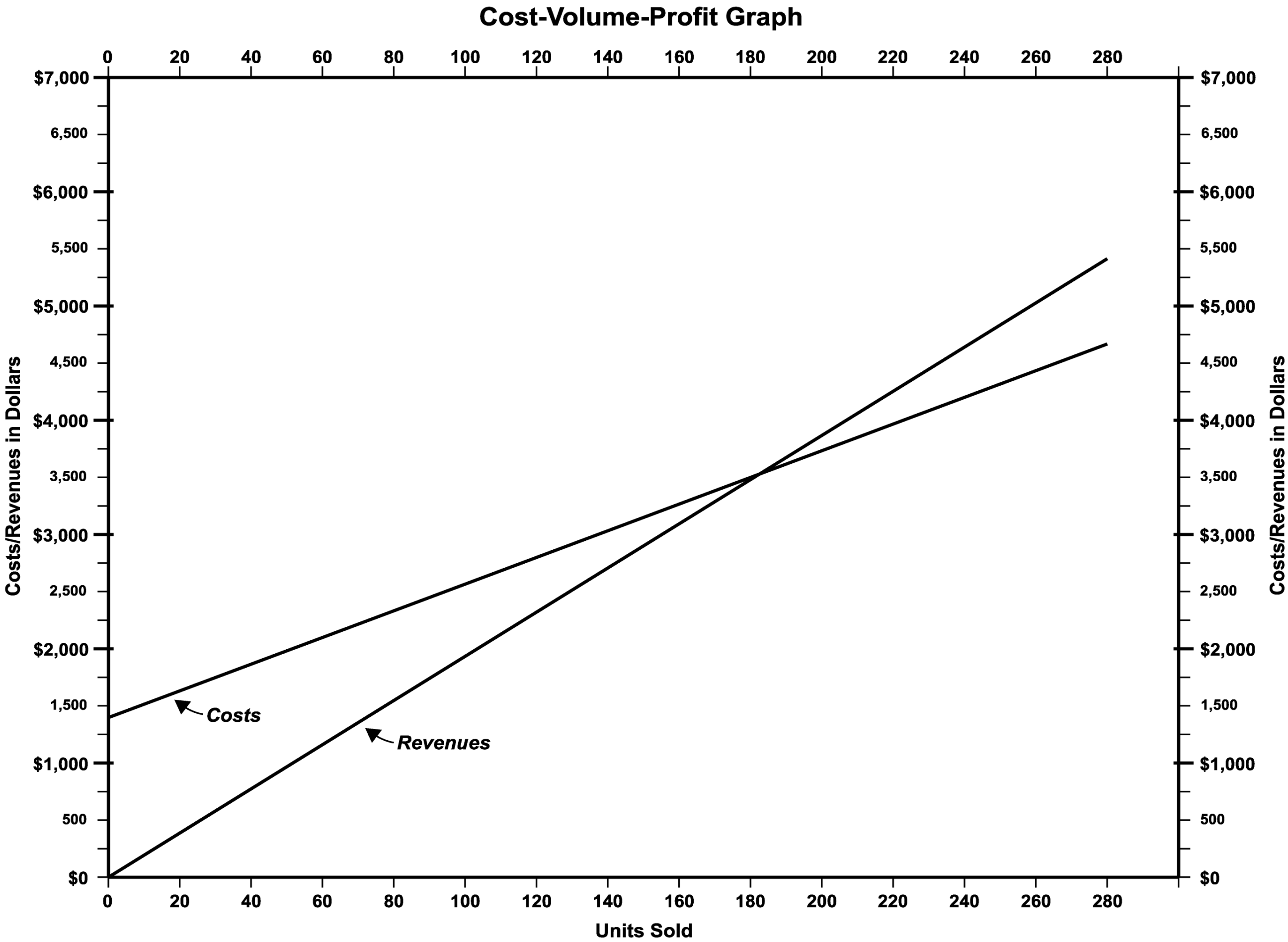


While the functions in Poulton's hypothetical graphs did not cross one another, a similar visual situation exists in the case of a C-V-P graph where two functions (total revenues and total costs) are plotted on the same two-dimensional graph. The total cost function is plotted "lower" than the total revenue function beyond the break-even point. This suggests that decision makers extracting data from a C-V-P graph will not only underestimate the values of both total revenues and total costs, but will underestimate total costs beyond the break-even point ***more*** than total revenues beyond the break-even point. This will result in an ***overestimate*** of profits – the relationship between the total revenues and total costs at a given level of sales.

The Reverse Effect

Poulton (1985) also notes a reverse effect that exists in the display of line graphs in a contextually neutral setting. The effect is illustrated by considering the C-V-P graph of Figure 4 (from this point on, the C-V-P graph of Figure 4 will be referred to simply as "C-V-P Graph 2"). C-V-P Graph 2 of Figure 4 includes two additional calibrated scales compared with C-V-P Graph 1 of Figure 2 – an ordinate calibrated scale on the right side and an x-axis (abscissa) calibrated scale on the top. Now if the total revenue line and total cost line are seen to be too flat but the corresponding dollar values are referenced from the right calibrated scale, then the reading of the values would be too high. Again, Poulton found this to be true in his experiments where decision makers extracted values from the end points (the far right end of the functions) of graphs displaying hypothetical data. The overestimation bias that was found was not as great as the underestimation bias found when subjects read values from a graph without the calibrated scales on the top and right sides of the graph (i.e., a graph similar in construction to C-V-P Graph 1 of Figure 2).

Figure 4. C-V-P Graph 2 – Four Calibrated Scales



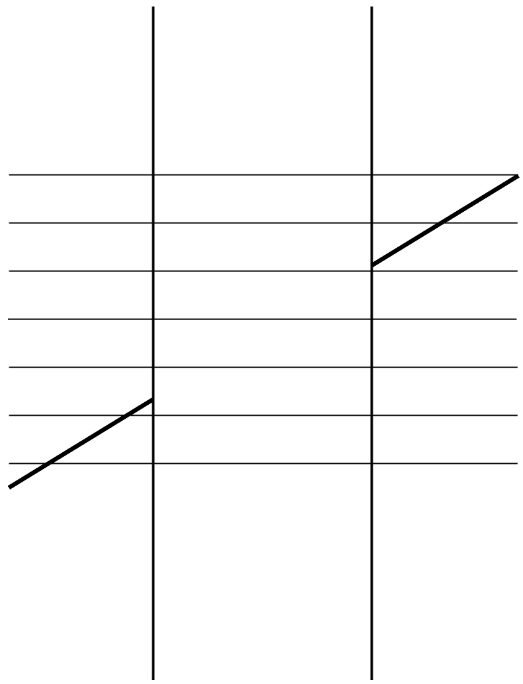
Adding Horizontal Gridlines – Overcoming the Bias

Poulton's work illustrates that a systematic bias results from the Poggendorff illusion when decision makers extract quantitative information from hypothetical two-dimensional line graphs: (1) An underestimation bias when reading data from a graph with only a left and bottom calibrated scale, and (2) a smaller overestimation bias when reading data from a graph with four calibrated scales. Based upon these findings, Poulton, and subsequently Gillan et al. (1998) and Wickens and Holland (2000, 121), set forth a graph preparation guideline: line graphs should be prepared to include calibrated axis on all four sides of the graph. The idea is to ***minimize*** the bias that results from the Poggendorff illusion. Based upon Poulton's second finding that bias is ***minimized*** when line graphs include four calibrated scales.

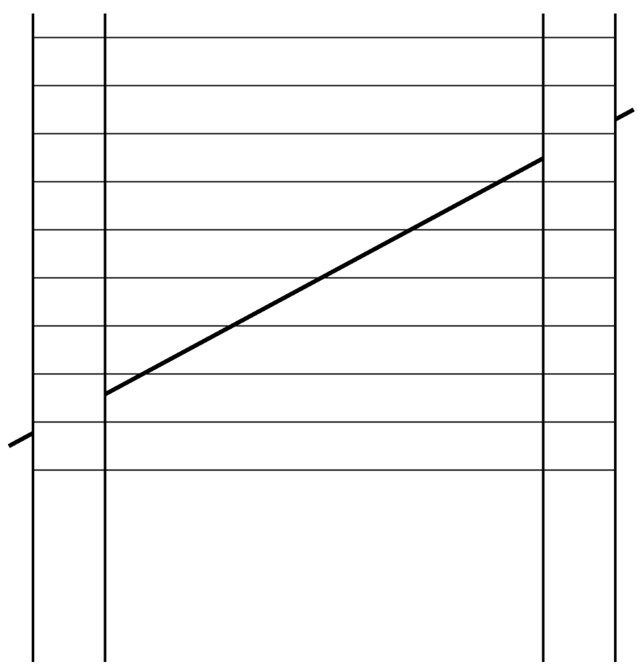
But, can the overestimation bias be overcome or moderated through proper graph design? Consider adding horizontal gridlines to line graphs. Indeed, this is a common feature available in graphing software. As seen in Figures 5.a. and 5.b., adding horizontal gridlines to the traditional Poggendorff figure and the "outside-in" version of the Poggendorff figure tends to reduce the visual illusion seen in Figures 1.a. and 1.b. The visual reference provided by the gridlines seems to allow the reader to see the components of the sloping line in proper perspective. In addition, Lawrence and O'Connor (1993) note that providing horizontal gridlines on graphs may provide an "anchor point" upon which decision makers can focus. Lawrence and O'Connor discuss this anchor-point notion in the context of a decision maker's estimate of confidence intervals on trend lines displayed on line graphs.

Figure 5. The Addition of Horizontal Gridlines to the Poggendorff Illusion

5.a. Addition of Gridlines to the Traditional Poggendorff Figure

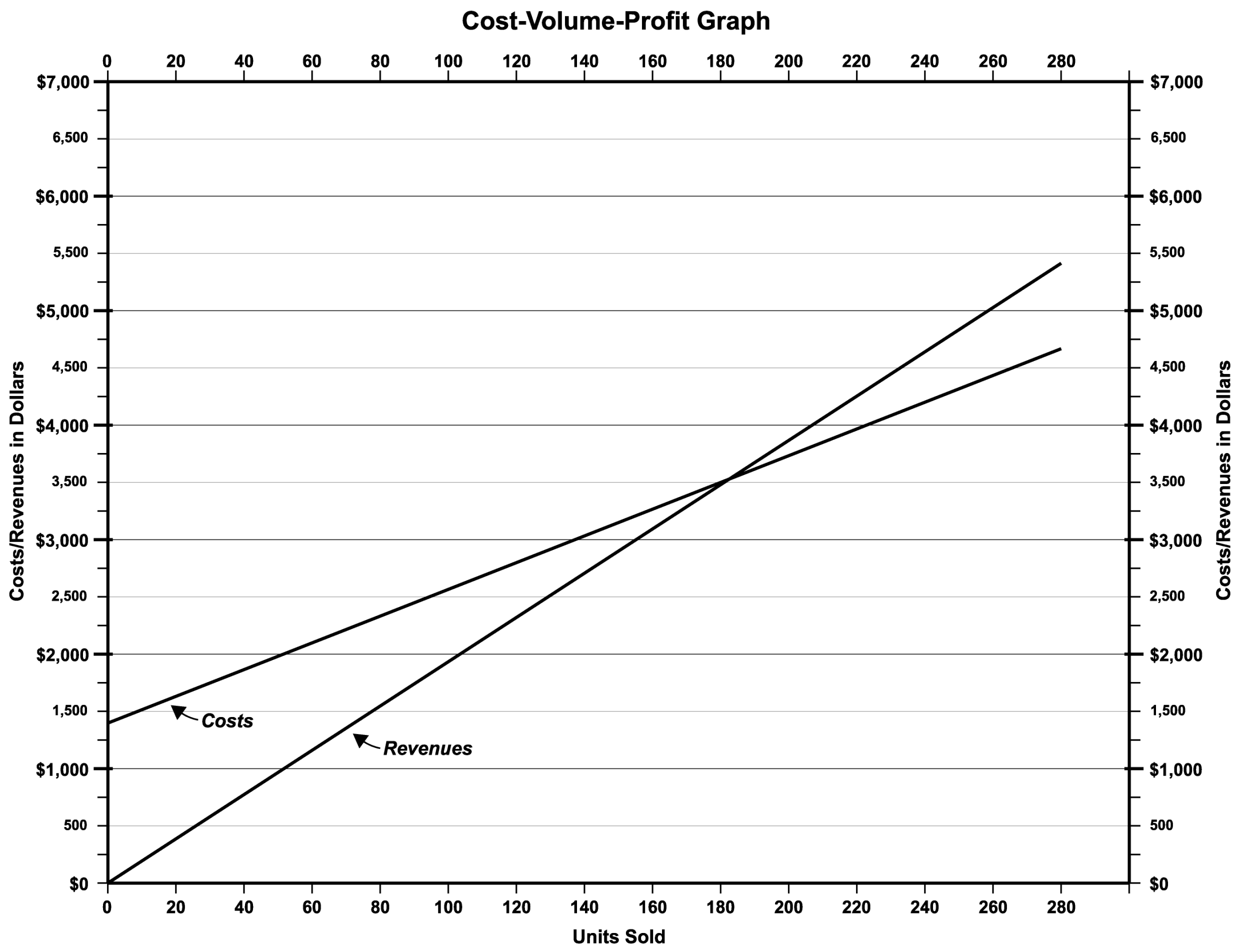


5.b. Addition of Gridlines to the "Outside-In" Poggendorff Figure



In the current context, such an anchor point may allow the reader to visually trace the values from the calibrated scales on the axis to the sloping lines and allow more accurate information extraction from line graphs. This may mitigate the bias resulting from the Poggendorff illusion. This visual mitigation can be seen in the C-V-P graph of Figure 6, which is identical to the C-V-P graphs of Figures 2 and 3 but with the addition of horizontal gridlines (from this point on, the C-V-P graph of Figure 6 will be referred to simply as "C-V-P Graph 3").

Figure 6. C-V-P Graph 3 – Four Calibrated Scales and Horizontal Gridlines



The notion of an anchor point discussed by Lawrence and O'Connor (1993) suggests that adding horizontal gridlines to line graphs may also result in another effect: reducing the variance in the values extracted from line graphs. The gridlines provide an anchor point from which a decision maker can first determine an approximate value on the lines within the graph. Then, each decision maker can refine his/her estimate by visually tracing along the gridline to the values on the calibrated scales. The process of extracting values from a graph without the gridlines as a reference is less precise because the decision maker has no defined visual reference from the point on the plotted line to the calibrated scales.

Hypotheses

The discussion of the Poggendorff illusion above leads to the following research hypotheses:

H1: Decision makers will ***underestimate*** the values extracted from line graphs when the line graph is constructed with only two calibrated scales: left and bottom.

H2: When multiple lines are plotted on a line graph constructed with only two calibrated scales (left and bottom) decision makers will more ***severely underestimate*** the values extracted from lines that fall below other lines.

H3: Decision makers will ***overestimate*** the values extracted from line graphs when the line graph is constructed with four calibrated scales: left and bottom, right and top.

Adding horizontal gridlines to line graphs results in two additional hypotheses:

H4: The effects noted in hypothesis **H3** above will be moderated through the addition of horizontal gridlines to a graph with four calibrated scales.

H5: The variance in the values extracted from line graphs will be reduced through the addition of horizontal gridlines to a graph with four calibrated scales.

IV. EXPEREMENTAL DESIGN AND METHODOLOGY

Overview

A laboratory experiment was carried out to examine the hypotheses set forth above. Subjects were randomly assigned to one of three groups. One group extracted values from a C-V-P graph with calibrated scales displayed only on the left and bottom of the graph (C-V-P Graph 1).[1] A second group extracted values from a C-V-P graph with calibrated scales displayed on all four sides of the graph (C-V-P Graph 2). A third group extracted values from a C-V-P graph similar to that of the second group but with the addition of horizontal gridlines (C-V-P Graph 3). The underlying information displayed was identical across all three treatment conditions. In addition, all three graphs were prepared according to the graph preparation guidelines noted earlier in this paper as set forth by Tufte (1983, 77).

Task

Arguably, one of the most commonly prepared and presented graphs in accounting and business is the C-V-P Graph. Indeed, an examination of one dozen newly published managerial accounting and cost accounting textbooks revealed that every one of these texts presented and discussed C-V-P graphs.

The high level of commonality and importance of this graph to accountants and managers provides an excellent context within which to examine the hypotheses presented in this paper. Subjects in each treatment condition were presented with C-V-P graphs on a computer monitor and requested to extract three values presented on the graph: (1) The amount of total revenues on the ordinate corresponding to the end-point of the total revenue line plotted on the graph, (2) The amount of total costs on the ordinate corresponding to the end point of the total cost line plotted on the graph, and (3) The amount of costs/revenues on the ordinate at the breakeven point – the point where the two lines cross.

The dependent variable measured was the difference between the dollar values extracted by each subject and the actual figures plotted on the graph. For example, the actual dollar value at the breakeven point displayed on each C-V-P graph is $3,530. If a given subject extracted the dollar value of $3,410 the difference of negative $120 would be considered an "underestimate" of the total revenue and total cost dollars at the breakeven point. Alternatively, if a subject extracted the dollar value $3,630, the difference of positive $100 would be considered an "overestimate."

Subjects

Ninety-six accounting students from a large public university participated in the experiment. These students were enrolled in accounting courses and all had been exposed to the principles of C-V-P and C-V-P graphs in their managerial accounting course. This instruction is compulsory for all business majors at the university and covers both the underlying concepts of C-V-P analysis as well as the preparation and use of C-V-P graphs. In addition, all subjects who participated in the experiment were presented with a review of C-V-P principles and graphing just prior to the administration of the experiment.

Student subjects are appropriate for the current study for the following reasons: First, much prior work on the usability and effectiveness of user interfaces has used student subjects (most recently Arunachalam, Pei, and Steinbart (forthcoming) and Tuttle and Kershaw (1998)). This general consensus supports the notion that students are appropriate for this type of work (see Dickson et al. (1986) and Locke (1986) for a discussion of this). Second, Ashton and Kramer (1980) concluded that in studies of decision-making, the decisions and underlying information processing behavior of students and primary decision makers were very similar. Third, it is important to note that this study is not concerned with the performance of decision makers in a professional context; rather, it is concerned with the decision processes associated with visual illusions in extracting information from line graphs. Finally, and as noted above, all subjects were trained in the principles and preparation of C-V-P graphs and were provided with a review of these

[1] Note that the graphs shown in the Figures of this paper are much smaller than those displayed to the subjects. The graphs viewed by the subjects were displayed as full screen images on a 17-inch CRT monitor.

concepts prior to administration of the experiment. Accordingly, it may be argued that the subjects were sufficiently proficient with the task to be representative of professional decision makers.

Procedure

All subjects were first provided with a review of C-V-P concepts and the preparation and use of C-V-P graphs during a regularly scheduled class period. Each subject was then randomly assigned to one of the three treatment conditions: A C-V-P graph with calibrated scales displayed only on the left and bottom of the graph (C-V-P Graph 1 of Figure 2); a C-V-P graph with calibrated scales displayed on all four sides of the graph (C-V-P Graph 2 of Figure 4); or a C-V-P graph similar to that of the second group but with the addition of horizontal gridlines (C-V-P Graph 3 of Figure 6).

Each subject was then instructed to sit in front of a computer monitor in a room with only the principal instructor present. The appropriate C-V-P graph was displayed as a full screen image on the monitor and the principal investigator, reading from a pre-prepared script, asked the subject to look to the end of the revenue line (at the point of 280 units on the horizontal axis of the graph) and state the dollar amount of revenues on the vertical axis of the graph. Each subject was instructed to state the amount to the nearest $10. Each subject was then asked to look to the end of the cost line plotted on the graph and state the amount of costs on the vertical axis of the graph. Finally, each subject was asked to look to where the two lines cross on the graph (the breakeven point) and state the dollar amount on the vertical axis of the graph at the breakeven point. The three values stated by each subject were used to calculate the dependent variable for analysis: the difference between the values extracted by each of the subjects and the actual values plotted on the graph.

IV. RESULTS AND ANALYSIS

Summary Statistics

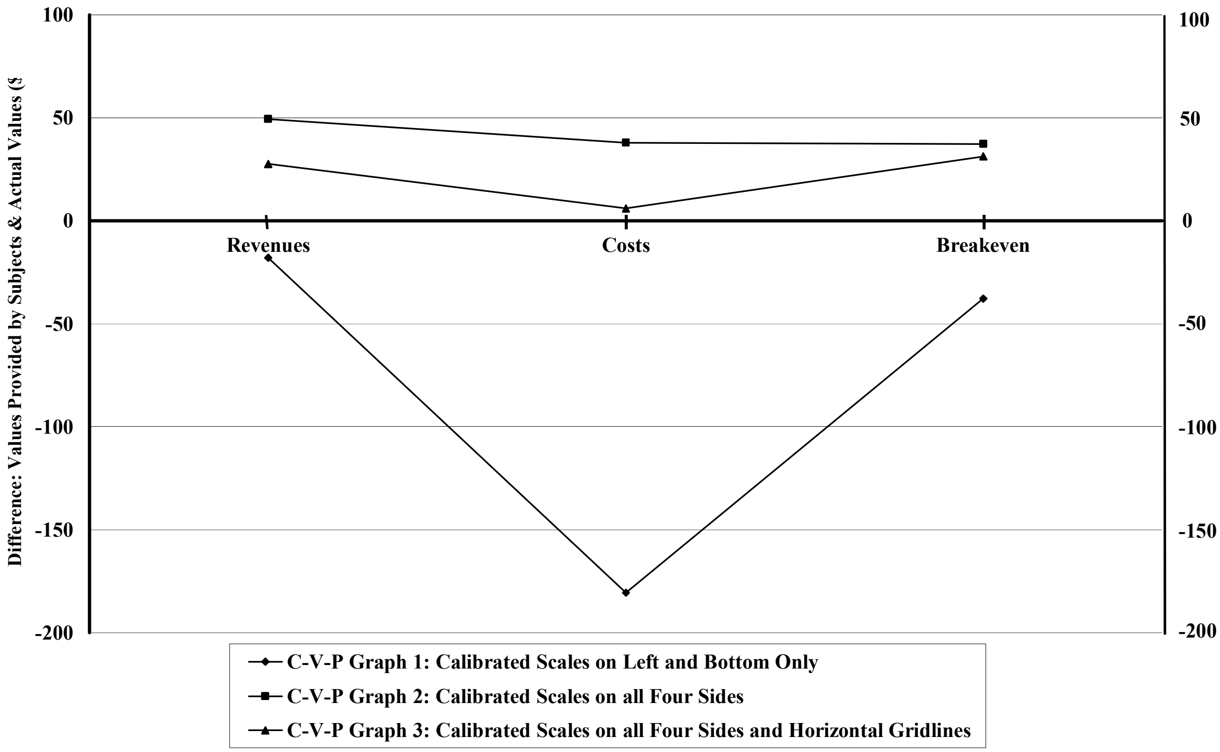
Table 1 and Figure 7 display the summary statistics for the dependent variable: the difference between the values provided by each subject and the actual values plotted on the graphs. An examination of the mean values displayed in Table 1 and Figure 7 indicates that, consistent with H1, the subjects who extracted values from the C-V-P Graph 1 of Figure 2 ***underestimated*** all three values (revenues, costs, and breakeven). Also note that, consistent with H2, the subjects using the C-V-P Graph 1 underestimated costs more than revenues.

Table 1. Mean Values of the Difference Between the Values Provided by Each Subject and the Actual Amounts Plotted on the Graphs (measured in dollars)

Graph Type	Difference Between the Revenue Values Provided by Each Subject and the Actual Revenue	Difference Between the Cost Values Provided by Each Subject and the Actual Cost	Difference Between the Breakeven Revenue/Cost Values Provided by Each Subject and the Actual Breakeven Revenue/Cost
C-V-P Graph 1: Calibrated Scales on the Left and Bottom (Figure 2)	-18.0 (131.1)*	-180.7 (166.6)	-37.7 (103.4)
C-V-P Graph 2: Calibrated scales on all Four Sides (Figure 4)	49.3 (32.2)	37.9 (43.7)	37.3 (101.5)
C-V-P Graph 3: Calibrated scales on all Four Sides and Horizontal Gridlines (Figure 6)	27.5 (38.1)	6.0 (60.7)	31.3 (27.9)

* Standard deviations are shown in parentheses.

Figure 7. Mean Values of the Difference Between the Values Provided by Each Subject and the Actual Amounts Plotted on the Graphs (measured in dollars)



Consistent with H3, the subjects who extracted values from the C-V-P Graph 2 of Figure 4 ***overestimated*** all three values (revenues, costs, and breakeven). Additionally and consistent with H4, the subjects who extracted values from the C-V-P Graph 3 of Figure 6 had lower deviations from the actual values than the subjects who used either of the other two graphs but for one value – the revenue figure for C-V-P Graph 1. This was especially true for the cost figure. It should be noted that as a treatment condition validity check subjects who extracted values from C-V-P Graph 3 were asked in a post experimental questionnaire if they had used the horizontal gridlines as an aid in extracting the values from the graph. All 32 of the subjects (100%) indicated that they had used the horizontal gridlines to help them extract the values from the graph.

These results are well illustrated in Figure 7, which displays the mean values of the dependent variable for all three treatment conditions. Note that the plot of the mean values for C-V-P Graph 1 falls below the other two plots. Also note that the plot of the mean values for C-V-P Graph 2 falls above the other two plots and, finally, that the plot of the mean values for C-V-P Graph 3 falls between the other plots.

Looking back to the data displayed in Table 1, the standard deviations are different across the graphs and, for the breakeven point, are smallest for the graph with the horizontal gridlines. This is somewhat consistent with H5. As will be discussed later, the horizontal gridlines had the effect of reducing the variance at only the break-even point because that point is displayed near the center of all three graphs, well away from the vertical axis from which the subjects could more easily reference the values presented on each of the three graphs.

Repeated-Measures ANOVA Analysis to Test Hypotheses H1, H3, and H4

The first analysis carried out was a repeated-measures ANOVA to determine if the graph treatments resulted in statistically significant differences in the dependent measures. The three values each subject extracted from the C-V-P graphs (the dollars of total revenues, total costs, and breakeven) is a within-subjects factor as each subject provided all three values from the same graph. The type of graph is a between subject factor because each subject viewed a different graph.

The multivariate Wilk's Lambda, Pillai's Trace, Hotelling-Lawley's Trace, and Roys Greatest Root all revealed a statistically significant treatment effect for the graph factor ($F(2,92) = 23.85$, $p < .0001$).[2] In addition, post-hoc tests revealed that each of the three graph treatments were statistically significantly different from one another. The dependent variable data from the graph C-V-P Graph 1 of Figure 2 was statistically lower than both C-V-P Graph 2 and C-V-P Graph 3 ($p < .0001$). Similar results were found when analyzing the relationship between the other two graphs: The dependent variable data from the C-V-P Graph 2 was statistically higher than both the C-V-P Graph 1 and C-V-P Graph 2 ($p < .0001$ and $p = .048$ respectively). Once again, these statistically significant differences are illustrated well in Figure 7. The plot reveals that the mean values for all three of the numbers extracted by the subjects (the dollars of total revenues, total costs, and breakeven) for each graph treatment "stack" according to the predictions stated in H1, H3, and H4.

Test of Hypothesis H2

Hypothesis H2 implies that the subjects using C-V-P Graph 1 of Figure 2 will underestimate the dollar amount extracted from the cost line more than the dollar amount extracted from the revenue line. This, in turn, will result in an overestimate of profits – the difference between the total revenues and total costs at a given level of sales. Support for this is illustrated in the bottom plot of Figure 7. This result is also shown statistically as the multivariate Wilk's Lambda, Pillai's Trace, Hotelling-Lawley's Trace, and Roys Greatest Root all revealed a statistically significant interaction between the treatment effect for the graph factor and the within-subject factor for the revenues, costs and breakeven dollar amounts extracted by each subject ($F(4,186) = 10.74$, $p < .0001$).

To more directly examine hypothesis H2, the data associated with the 31 subjects who extracted values from the C-V-P Graph 1 were analyzed. A pairwise t-test analysis was conducted to determine if the value the subjects extracted from the total cost line deviated more from the actual value than the value the subjects extracted from the total revenue line. As shown in Table 1 and Figure 7 the mean of the difference between the revenue value provided by each subject and the actual revenue (the deviation) was negative 18.0. The difference between the cost values provided by each subject and the actual cost was negative 180.7. The results from the pairwise t-test show a strongly significant difference between these measures ($t = 5.93$, $p < .0001$).

Test of Hypothesis H5

Hypothesis H5 indicates that the variance in the values extracted from C-V-P Graph 3 of Figure 6 should be lower than the variance in the values extracted from the other two graphs due to the existence of the horizontal gridlines. An examination of the standard deviations displayed in Table 1 reveals differences in the variations but not exactly in the pattern predicted.

First, consider the standard deviations for C-V-P Graph 1 in the top row of Table 1. There is relatively high variance for the data associated with all three points (revenue, costs and breakeven). An examination of C-V-P Graph 1 of Figure 2 reveals that this is likely due to the complete lack of a reference scale near to these points on either a calibrated axis or via a horizontal gridline. Accordingly, each subject would have to reference the values form the lines plotted in the graph from the left axis. The left axis is a relatively large visual distance from the end points of both the revenue and cost function, as well as from the breakeven point appearing near the center of the C-V-P graph.

Now consider the standard deviations for C-V-P Graph 2 in the middle row of Table 1. There is relatively low variance for the data associated with the revenue and cost points but high variance for the breakeven point. An examination of C-V-P Graph 2 in Figure 4 reveals a potential explanation. There is a reference scale on the right axis of the C-V-P Graph 2 that is a very small visual distance from the end points of both the total revenue and total cost functions. The closeness of the reference scale most likely allowed the subjects to more precisely determine the values at the end of both the total revenue and total cost functions. Such was not possible for the breakeven value, however, which was plotted near to the center of the C-V-P graph, a much larger visual distance from the nearest reference scale.

Finally, consider the standard deviations for C-V-P Graph 3 of Figure 6 shown in the bottom row of Table 1. There is relatively low variance for the data associated with all points (revenue, costs and breakeven). This can be attributed to the existence of the visually close reference of the horizontal gridlines. Specifically note the

[2] As can be seen from the data of Table 1, the variances between graph treatment conditions are not equal, thus violating one assumption of ANOVA. Indeed, unequal variance between the treatment conditions is hypothesized in **H5** and was therefore anticipated. Several transformations to the data were carried out as a remedial measure including a square root, log and, reciprocal (Neter et al. 1996). The results from these analyses mirrored those reported in the body of the paper for non-transformed data.

relatively low standard deviation of the data associated with the breakeven point shown in the bottom right cell of Table 1. This standard deviation is statistically lower than that associated with the breakeven data of both C-V-P Graph 1 and C-V-P Graph 2 displayed in the cells just above in Table 1 ($F = 13.69$, $p < .0001$ and $F= 13.19$, $p < .0001$ respectively). This is consistent with hypothesis H5 in that the existence of the horizontal gridlines of C-V-P Graph 3 resulted in a lower variance for the data associated with breakeven point. In both C-V-P Graph 1 and 2 the breakeven point is plotted a relatively large visual distance from a reference scale resulting in larger variances.

V. Discussion And Conclusions

This paper reports the results of an experiment carried out to examine the effect of a visual illusion on the values decision makers extract from a graphical presentation of information. The results indicate that decision makers can fall prey to the so-called "Poggendorff illusion" and either systematically underestimate or systematically overestimate the values displayed on a C-V-P graph. In addition, the results of this research suggest that the bias can be moderated by the inclusion of horizontal gridlines on line graphs. The addition of horizontal gridlines also reduces the variance in the values decision makers extracted from the center of graphs. Accordingly, a graph preparation guideline should be followed to avoid the bias and high variance in information extraction – Horizontal gridlines should be included on all line graphs.

Limitations

There are a few limitations of the experiment reported in this paper that should be noted. First, the use of student subjects may raise questions about the validity of the results. However, as noted earlier in this paper the subjects had a-priori knowledge of both the use and preparation of the C-V-P graphs used in this study. In addition, they were provided with a review of these concepts before the administration of the experiment. Although caution should be exercised in generalizing the findings of this study, the results could be extended to a professional setting. Finally, the subjects in this study had considerably more understanding and experience in the decision setting than subjects reported in the human factors psychology literature, as they were trained in and familiar with both the presentation and preparation of C-V-P graphs.

A second limitation relates to the task completed. The subjects extracted values only from the end points of the total revenue and total cost lines on each graph. Accordingly, the results reported may not hold for other points on the functions, for example, points closer to the left axis. However, the subjects did extract values from points close to the center of each graph at the breakeven point and in general, the predictions hypothesized were supported by this data. Regardless, future research could be carried out to address this issue.

Implications for Practice

A few guidelines clearly result from the findings reported in the paper. First, in addition to the six preparation guidelines noted earlier and in prior literature (Arunachalam, Pei, and Steinbart, forthcoming and Tufte, 1983, p. 77) line graphs should contain labeled scales on all four sides and include horizontal gridlines. The inclusion of these features will not only reduce the bias that can result when decision makers extract information from graphs but also reduce the variance in some of the values extracted. This bias has an especially interesting implication for users of C-V-P graphs. Consider C-V-P Graph 1 of Figure 2 that features calibrated scales on the left and bottom only. Given the results that subjects using this graph underestimated total costs more than total revenues, implies that they would ***overestimate*** profits, a "non-conservative" result.

The power possessed by most computerized graphical programming tools allows these two features to be added to a graph for a very low cost. Indeed, Microsoft's Excel spreadsheet program, arguably the most ubiquitous and easy to use graphics-capable package, includes simple menu options that allow the user to add gridlines to graphs. Still, there is a paucity of graphs that include such features. For example, an examination of one dozen newly published managerial accounting and cost accounting textbooks revealed that while all presented C-V-P graphs, only one textbook displayed a C-V-P graph with horizontal gridlines.

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