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How Bar Chart Display Features Can Skew Perception

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Abstract

This study empirically examines three display design features that can hinder or promote viewers' perceptual bias of bar charts. Bar charts are commonly used in various landscapes, including business contexts, yet, research on their impact on bias is limited. In an experiment, 266 undergraduates viewed vertical bar charts with two styles of scaling (fine vs coarse), two formats of bar ordering (in a certain order vs in random order) and two patterns of bar width (same vs different). A 7-item quiz measured the level of perceptual bias. Results showed that the main effects of all three display features. The results revealed that the interaction of bar ordering formats and (1) the scaling styles and (2) the bar thickness patterns on viewers' perceptual bias were significant. The other effects were not. In addition to extending the theoretical insight into visual deception in the contexts of bar charts, the findings provide practical guidelines for visual makers on bar chart designs that could lead to readers' perceptual bias, and for visual viewers on how to properly decode the meaning embedded in bar charts.

Keywords: *Bar Chart, Perceptual Bias, Scaling, Bar Ordering, Bar Width.*

Introduction

The bar chart is a fundamental tool in data visualization, widely used across disciplines. Its design allows for the clear presentation of data, facilitating the understanding of relationships among distinct categories or persuading viewers to follow what visual makers attempt. Its effectiveness lies in its simplicity and the ease with which it can convey complex information briefly.

Bar charts are particularly effective in displaying categorical data. Each bar represents one category, and the height of the bar corresponds to the value associated with that category. This visual representation allows for comparisons between categories, making it easier for viewers to discern patterns. For instance, in the context of health communication, bar charts have been shown to enhance patient understanding of risk information, as they can visually represent the likelihood of outcomes in a straightforward manner (Carey et al., 2018). However, bar charts also have limitations in representing negative values. While they can effectively display both positive and negative values by extending bars in opposite directions, this can lead to confusion if not clearly labeled (Scherr et al., 2012).

Bar charts are a prevalent form of data visualization that can significantly influence how information is perceived and interpreted. However, they are not without biases, which can lead to misinterpretations of the underlying data. The perceptual bias is rooted in the visual estimation and comparison strategies individuals employ while visualizing a bar chart. Such bias is in line with the common business practice of visual perception (Baek, et al., 2017). Referring to the manipulation of visual information to influence perceptions, it has significant implications for business data presentation. The visual perception could manifest in business through the design of bar charts (Zacks, et al., 1998). Perceptual bias due to visual perception has both negative and positive implications for business.

The negative outcome of perceptual bias concerns the viewer's misunderstanding of bar charts, leading to their trust erosion (Haselhuhn, et al., 2017). For this negative notion, it is coined as visual deception (Wang, et al., 2022). Viewers whose understanding of bar charts was twisted had an unhealthy relationship with the firms associated with the charts (Elangovan, et al., 2007). Despite the negativity, visual perception does have a positive contribution. The visual cue of electronic commerce websites has led to high purchase

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intention (Chonpracha, et al., 2020). Companies experiencing financial hardship often create charts that could legally persuade viewers to perceive manageable financial issues and consequently continue investing with them.

Bar chart display factors have been researched to discern which design could enhance viewers' understanding or could minimize their perceptual biases. For instance, animated and static backgrounds of bar charts were confirmed using an experiment to have similar effects on Thai high school students' comprehension of bar charts (Tangmanee & Jittarat, 2013). The impacts of internal contrast and framing enhancement on perception in bar charts were addressed in Diaz, et al. (2018). A review of charts published in corporate annual reports confirms that firms have often used nontraditional display styles to deceive viewers for business reasons. Of our research interests are scaling granularities on the Y-axis, bar ordering formats, and bar width patterns. The first refers to whether the Y-axis of the charts is finely or coarsely scaled, the second is whether the vertical bars are in random order or in ascending order, and the third refers to whether the width of the bars are of the same or of the different thickness. Each of these three display factors has been the focus in visualization research (Talbot, et al., 2014; Skau, et al., 2015; Okan, et al., 2018). However, virtually no project has addressed all three variables or their effects on viewers' perceptual bias. Our main research objective is therefore to verify these impacts on bias.

Literature Review

Bar charts are a fundamental data visualization method, commonly used to map categorical data onto visual displays for numerical comparisons (Huang et al., 2009). They consist of rectangular bars where the height represents the data value, making them effective for conveying information (Talbot et al., 2014). Bar charts using length encodings are more effective for displaying quantitative data compared to other types of charts like Treemaps (Kong et al., 2010). Additionally, the use of physical representations, such as physical bar charts, can enhance memorability compared to digital on-screen representations, suggesting the importance of considering display factors in visualization (Stusak et al., 2015).

The wide acceptance of bar charts in business settings can be a result of their utility in conveying numeric details. Bar charts serve as a fundamental tool in data visualization, allowing users to compare various categories of data through the visual representation of bar heights. This visual encoding is intuitive, making it easier for viewers to grasp complex data sets quickly. Research has demonstrated that bar charts are particularly effective in contexts where precise comparisons are necessary, such as in business reporting and performance analysis (Kerr, 2021; Hlawatsch et al., 2013).

In the realm of business, bar charts are commonly employed to present business data for managerial decision-making, highlighting their role in providing a clear visual representation across projects (Kerr, 2021). This aligns with findings from Hlawatsch et al. (2013) who note that bar charts facilitate intuitive exploration of quantitative data, allowing stakeholders to make informed decisions based on visual insights. Furthermore, a systematic review by Albers et al. (2022) indicates that bar charts are preferred over other visualization formats in clinical settings, suggesting their broad applicability in presenting longitudinal data effectively.

Given the enormous uncertainty in running today's business, firms may experience certain difficulties, some of which could be alleviated using additional investment. Should this difficulty be known to outsiders, the chance that investors would pour money into the firms could be slim or even impossible. Yet, the firms are bound by law to report the difficulties to the public through their annual statement. Hence, companies must report financial hardship while persuading the public or investors to make more investment. One of the persuasion techniques is through visual deception. A manipulation of a visual cue to influence one's perception, the visual deception carries both negative and positive connotations.

Regarding the negative notion, especially in business settings, visual deception often holds unethical implications, leading to trust erosion or inaccurate communication among various stakeholders (Gneezy, 2005). This would complicate the dynamics of trust in business relationships (Haselhuhn, et al., 2017). During business negotiations, bluffing (e.g., verbal, or nonverbal deception) is known as one of the winning

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strategies between buyers and suppliers (Kaufmann, et al., 2017). The perceptual bias due to the deception also extends to the consumer context. Buyers are more likely to withdraw from future purchases when they perceive deception (Wang, et al., 2022).

Visual perception does have a positive side. One of the constructive ways it manifests in business is through the design of charts. Studies have shown that the way data is visually presented can significantly impact how it is perceived (Fabil, et al., 2012; Yu, et al., 2022). Marketers can intentionally design packaging and advertising visuals to evoke specific emotional responses, potentially leading consumers to make decisions based on manipulated perceptions rather than objective evaluations of the product (Pochun, et al., 2018; Fan, 2023). Such strategies can enhance brand loyalty and influence purchasing behavior, but they also raise ethical concerns regarding consumer manipulation.

In the realm of organizational decision-making, visual tools can both aid and hinder effective choices. For example, Yan, et al. (2022) explored how integrated knowledge visualization can support strategic management decisions by providing real-time data inputs and simulations. However, if these visualizations are poorly designed or deceptive, they can lead to suboptimal decisions which may benefit the other side. The balance between effective visualization and the risk of visual deception is critical, as organizations must navigate the fine line between persuasive design and ethical representation of information. For example, a survey on earnings management provides insights into the broader implications of visual deception in financial reporting (Nagy, 2022). By employing visual techniques to manipulate financial data presentation, companies can create illusory impressions of their financial performance, which can ultimately lead to significant consequences for investors and the market.

Scaling granularities of the Y-axis, bar-ordering formats and bar width patterns are among several display factors on which previous work has remarked on whether they affect viewers' perception. Nonetheless, the amount of empirical work in business settings that supports this remark is small. Among them are those papers addressing how a truncated Y-axis would affect bar chart interpretation (Long, 2024), papers examining the distances between bars (Skau, et al., 2015), and papers investigating how varying bar widths could create perceptual bias (Okan, et al., 2018). Y-axis scaling styles in our study refer to how values on the axis are arranged. The fine scaling could be preferable to a rough one since it seems to help viewers to better decode the bar chart detail. Yet, this statement is valid only when the range of all Y-values is not too wide. Despite the available big screen for the display, a remarkable number of viewers often rely on their mobiles to observe online content (Kantabutra & Tangmanee, 2024). It is thus inevitable that chart makers must adopt coarse scaling so the display of the entire chart can fit in a mobile screen. However, empirical work addressing these two styles of scaling is relatively rare.

Regarding the ordering of all bars on the X-axis, most of previous work has looked at the bar orientation or the distances between adjacent bars. Skau, et al. (2015) confirmed the significant effect of spacing between bars on readability and visual task performance. Among other display factors, the bar orientation had a significant impact on chart comprehension (Tangmanee & Jittarat, 2013). Beside few publications addressing bar ordering, no studies have verified its effect on viewers' perceptual bias.

Based on the Gestalt principles of perception, the bars with unequal width could lead to viewers' misinterpretations (Okan, et al., 2018). In the systematic review of visualization research in clinical settings, Albers, et al. (2022) remarked that the unequal thickness of bars on familiar charts affected clinician's perception of accuracy of patient-reported charts. In the field of data science, bar chart viewers have bias, especially when the widths of the bars differ; such bias emphasizes the need for careful design of bar width (Riedel, et al., 2022; Xiong, et al., 2022).

In summary, while previous research has addressed the effects of various display factors on bar chart comprehension, two research gaps have emerged. First, although a number of the display factors have been examined, virtually none has incorporated all three display features in the same research project. This is not to mention the different operationalizations of these three features. Second, most of the past work on visualization has concentrated on chart comprehension or understanding. While perceptual bias has a negative connotation, it has been proved using the visual deception concept to greatly benefit firms.

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However, no publication has examined which display factors contribute to viewers' perceptual bias while visualizing a bar chart. Hence, we attempted to fill these two gaps, and our main objective is to assess whether the effects of the scaling styles on the Y-axis, bar ordering formats and different bar width patterns on perceptual bias are significant.

Research Methodology

To respond to the research objectives, we discuss four methodological issues: research design; chart content and variable operationalization; experimental execution; and data analysis and hypothesis testing.

Research Design

To assess the effects of Y-axis scaling styles, bar ordering formats and width patterns on viewers' perceptual bias, we opted for an experimental approach. We manipulated three independent display features, controlled other variables, and observed their effects on bias in visualizing bar charts. Should there be an observed effect, it should be valid and reliable (Babbie, 2013).

Chart Content and Variable Operationalization

To ensure the effect of the three display factors on viewer's perceptual bias, it was important that the chart contents with different display designs had to be comparable. The chart contents in this research were the sale figures (i.e., the number of sold items) of ten automobile brands in 2020. They were selected because the details are generally of public interest, and we also believe that managers would want to read a chart to bolster their target's perception that their sale figures are higher than its competitors. In addition, the contents of our trial charts do have certain business implications.

The chart content of automobile sale figures allows us to manipulate (1) the scaling of the Y-axis, (2) the ordering of the vertical bars, and (3) the bar thickness patterns while controlling the other variables. The scaling of Y-axis was operationalized in the current research as holding two values: fine and coarse scaling. A multiplication of 15,000 cars represents the former and that of 40,000 ones denotes the latter. The rationale behind these two values was based on the range of our data and the chart appearance on a display screen. The bar ordering has two values. The first is that all bars are arranged in ascending order of the Y values, while the second refers to the arrangement in random order. Please note that the random order was set the same throughout the entire experiment. The bar width patterns have two possible values. The first depicts all bars having the same width and the second denotes all bars having varying width. Similar to the operation of the bar ordering formats, the second value of the width pattern was set the same throughout the experiment. Given the Thai subjects in this study, most of the details on the chart were in Thai. Only the names of the automobile were in English. Figures 1 and 2 show, firstly, a chart in which all bars are of varying width and randomly ordered with fine scaling and, secondly, a chart in which the bars are the same width and in ascending order with coarse scaling.

To measure perceptual bias, we developed seven multiple-choice questions to ask viewers while visualizing the charts. All seven items are available upon a request to the first author. If their replies were incorrect, the subjects must have perceptual bias. That is, they earned zero points for the correct reply and one point for the incorrect answer. Hence, the maximum and the minimum points of a subject's perceptual bias are seven and zero, respectively. Our items measuring a viewer's perceptual bias ask how they interpret or perceive the chart detail. Such perception includes observing the specific value (e.g., How many Honda cars were sold?) or comparing two sale figures (e.g., Were BMW sale figures higher than Honda's? or By how many cars did MG outsell Ford?). We made no attempt to capture their cognitive bias. As a result, our items are rather simple so viewers should be able to share their perception quickly after looking at the charts. In other words, they could reply to the items without making a cognitive effort. After a few rounds of pretests with twelve students and two faculty members, the items seem to capture the subject's perceptual bias.

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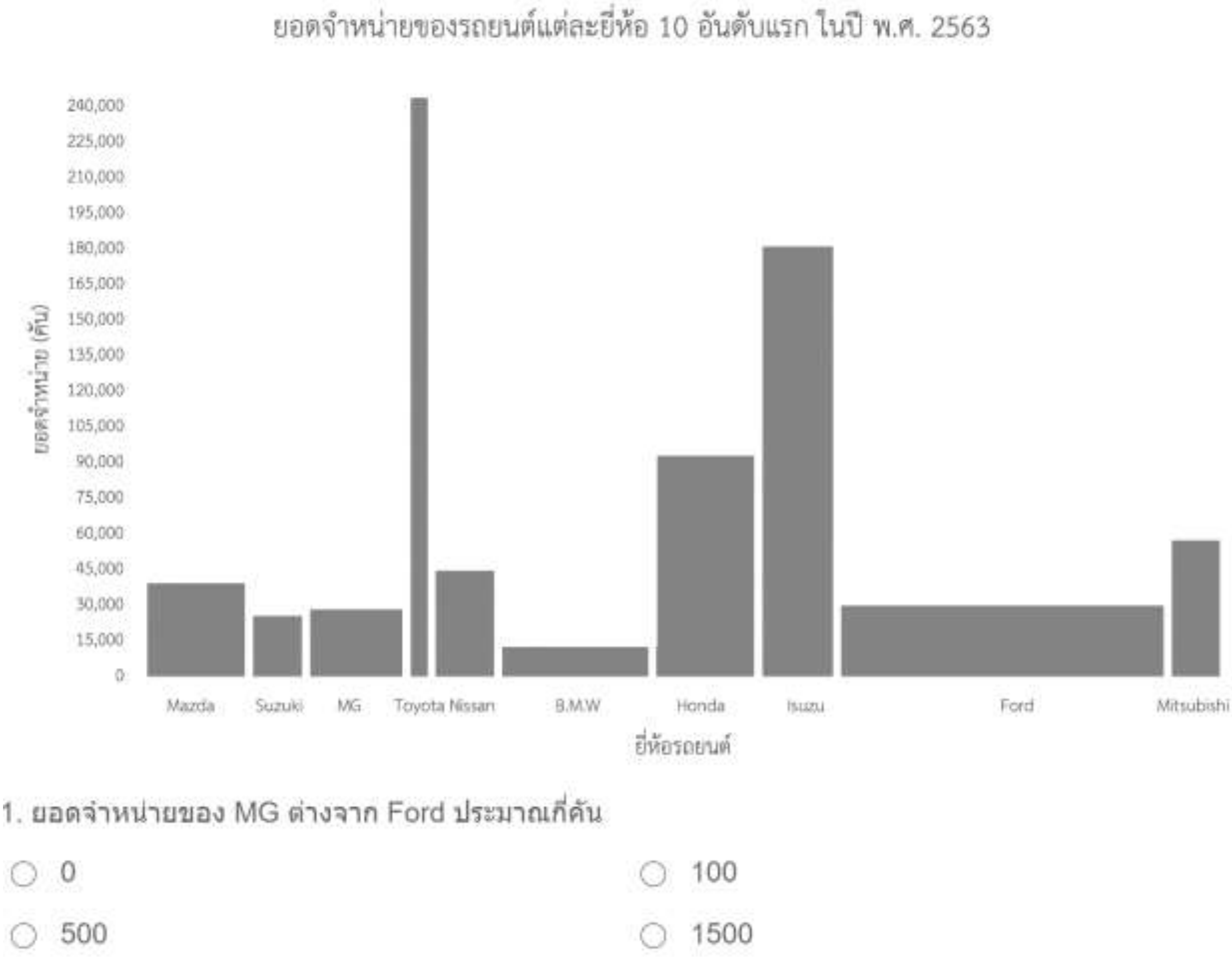
Figure 1. Experimental Chart with Fine Scaling and All Bars in Random Order and Of Different Width.



Experimental Execution

We developed eight bar charts based on the three display features (two styles of scaling x two types of bar ordering x two patterns of bar width). The charts were created with identical details using Excel, which is part of Microsoft Office (Version 20h2). Many default features in Excel were used to create the charts so research replication will be likely. For instance, the distance between adjacent bars or the bar widths was set by the application default.

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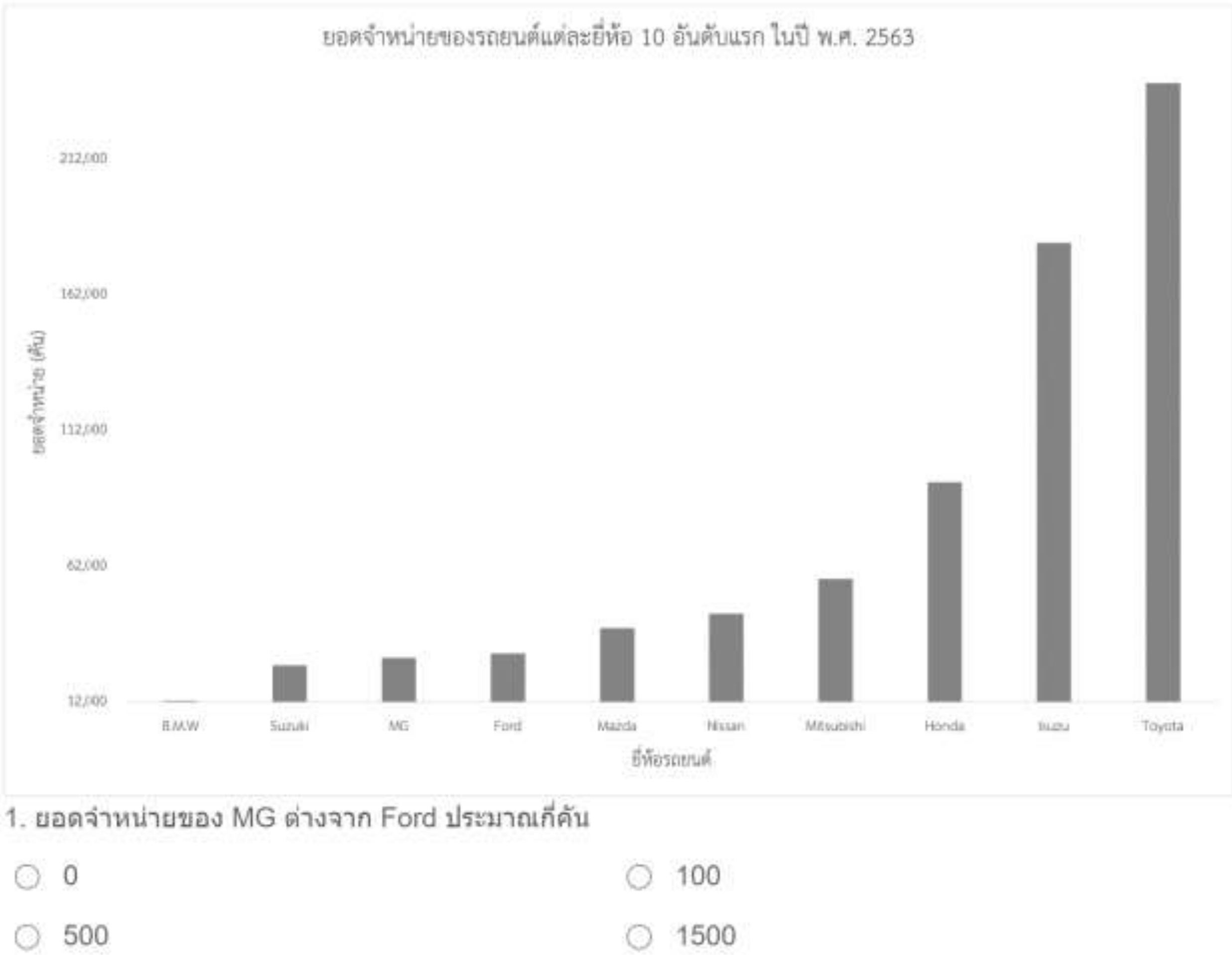
Figure 2. Experimental Chart with Coarse Scaling and All Bars in Ascending Order and Of the Same Width.



We initially planned to have a lab experiment at computer labs in Chulalongkorn Business School and the participants in our research would be recruited from a pool of undergraduates. Such comparable credentials among the subjects are essential in an experiment. The COVID-19 breakdown had, however, halted our plan. We thus posted a call for research participation through multiple social media channels to invite subjects. After clicking on a link in the message, the participants had to respond to a few screening questions that will ensure their comparable background, thereby enhancing the research validity. Only those who passed the screening questions would see the instructions, the bar chart, and the items measuring the perceptual bias. The order of the quiz items was randomly shown on each subject' display screen. This is to minimize the effect of the item order. At the end of data collection, the subjects would answer a few questions on their demographics to help interpret the results.

Analysis and Hypothesis Testing

We reported descriptive statistics of major variables and used an analysis of variance (ANOVA) test to verify whether the three display features have significant effects on viewers' perceptual biases. As a result, the corresponding hypothesis statement is the main and the interaction effects of the two factors were significant.

Results

During March of 2022, we were able to have a total of 266 subjects participating in our experiment. Based on the eight groups of our trial bar charts (2 styles of scaling on the Y-axis x 2 formats of bar ordering x

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2 patterns of bar width) with identical contents, the 266 subjects were considered adequate (Babbie, 2013). All subjects were undergraduates in Chulalongkorn University's business school. 67% of the subjects were women and about the half were senior students.

The descriptive statistics of the subjects' perceptual bias are shown in Table 1. Based on the total number of 266 subjects, their perceptual bias on average was 2.77, with a range of 0 to 7 and a standard deviation of 1.365. Because the absolute values of the skewness and the kurtosis statistics in Table 1 were less than one, the perceptual bias in the current study is normally distributed (Mulylle, et al., 2014). This allows us to perform a parametric data analysis. In addition, the small average may signify that the subjects largely understood the experimental bar charts. Further discussion will be in the conclusion section.

Table 1. Descriptive Statistics of Perceptual Bias Classified by Two Display Factors

Display features	Count	Mean	Standard deviation	Skewness	Kurtosis
Scaling styles on Y					
Fine	133	2.48	1.368	0.193	-0.204
Coarse	133	3.05	1.305	0.213	-0.035
Bar ordering formats					
In ascending order	135	2.50	1.309	0.352	0.362
In random order	131	3.05	1.369	-0.047	-0.257
Bar width patterns					
Same width	140	2.46	1.231	0.053	-0.345
Varying width	126	3.11	1.427	0.070	-0.136
Total	266	2.77	1.365	0.159	-0.135

Regarding the two styles of scaling on Y, those subjects who observed trial bar charts with fine scaling had less perceptual bias than those who read the charts with coarse scaling (see Table 1). For the two formats of bar ordering, those who viewed the charts with bars in random order perceived a larger amount of bias than those who witnessed the charts with bars in ascending order. Finally, those who observed the charts on which all bars had the same width noticed a lower amount of perceptual bias than those who saw the chart where all bars had a different width. Such differences further require statistical analyses, the results of which are in Table 2.

Based on Table 2, the main effects of all three display factors on the subjects' perceptual bias were significant. The analysis of the interaction of the bar-ordering formats and the Y-axis scaling styles and that effect of the bar ordering formats and the bar thickness patterns on viewers' perceptual bias were also significant and are included in Tables 3 and 4. When the bars were in ascending order, the amounts of bias when the y-axis was finely- and coarsely-scaled were comparable for the p-value of 0.367. However, when the bars were in no particular order, the amount of perceptual bias when the scale of the chart's y-axis was fine was significantly lower than when the scale was rough. Similarly, when the bars were in an ascending order, the perceptual bias when viewers observed the charts with all bars the same width was comparable to the bias when viewers saw the charts with all bars being of different width, with the p-value of 0.140. However, when the bars were in no particular order, the perceptual bias between the two conditions was significantly different. Further discussion on how to display a bar chart that could minimize viewers' perceptual bias will be in the next section.

Table 2. ANOVA Results

Source of variance (SOV)	Sum square error (SSE)	Degree of freedom (df)	Mean square error (MSE)	F statistics	P-value
Scaling on Y	22.265	1	22.265	14.507	.000
Bar ordering	20.924	1	20.924	13.634	.000
Bar thickness pattern	32.884	1	32.884	21.426	.000
Scaling on Y x Bar ordering	13.623	1	13.284	8.877	.003

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Scaling on Y x Bar thickness pattern	0.789	1	0.789	0.514	.474
Bar ordering x Bar thickness pattern	8.429	1	8.429	5.492	.020
Scaling on Y x Bar ordering x Bar thickness pattern	2.926	1	2.926	1.906	.169
Error	395.966	258	1.679		
Total	2,530.000	265			

Table 3. Comparison Of Perceptual Bias Across Two Styles of Scaling on Y For a Given Format of Bar Ordering

Two formats of bar ordering	Two styles of scaling on Y		t-statistics (df)	P-value
	Fine	Coarse		
In ascending order	2.44	2.55	-0.339 (131)	0.367
In random order	2.52	3.53	-4.633 (131)	0.000

Table 4. Comparison Of Perceptual Bias Across Two Patterns of Bar Thickness for A Given Format of Bar Ordering

Two formats of bar ordering	Bar thickness patterns		t-statistics (df)	P-value
	Same	Varying		
In ascending order	2.33	2.67	1.485 (133)	0.140
In random order	2.58	3.60	4.573 (129)	0.000

Discussion

From the analytic results, all subjects are undergraduates of Chulalongkorn Business School at Chulalongkorn University, Thailand. Hence, it is reasonable to assume academic compatibility among them, especially in terms of their experience with visual charts. Moreover, 2 in 3 of the subjects are female. Such a proportion was in line with what was reported in the school profile (Office of Registrar, 2024). As a result, the subjects in our study were (1) representative of those who would later consume visual data in an actual business environment and (2) proper participants in an academic experiment.

Based on the total of 266 participants in our experiment, the average of their perceptual bias was 2.77 from its range between 0 and 7. The low scores of the bias may indicate (1) our subjects were well capable of understanding the charts with nontraditional designs or (2) the chart design may not be so deceptive, especially for this group of viewers. Since we are unable to locate the empirical work that reported the perceptual bias in similar contexts, we must challenge scholars to replicate this research landscape.

The main effect of the scaling styles on the Y-axis, the bar-ordering formats and the bar width patterns on viewers' perceptual bias are all significant in our research. Given the experimental approach, such causality is valid and came as no surprise. Those who observed the bar charts with fine scaling of a multiplication of 15,000 had significantly less bias than those who saw the charts with coarse scaling by a factor of 2 to 1. This finding is similar to what occurred in previous work, a few of which had addressed the differences between fine and rough scaling of bar charts. In their four experiments, Talbot, et al. (2014) discovered that viewers were generally more accurate when their comparison was made based on the finely scaled charts than when they were made based on the roughly scaled charts. In other words, the bias when viewers observed coarsely scaled bar charts was larger than that when viewers saw finely scaled bar charts. It is also evident in Sandnes, et al. (2020) that the visual perception of the bar charts with rough scaling is faultier than that of the charts with fine scaling.

Also in our experiment, the viewers who read the charts when the bars were in ascending order had less bias than those who decoded the bars in a random order. This finding is consistent with those in previous reports. The systematic arrangement of bars could facilitate better visual perception than the odd arrangements (Talbots, et al., 2014). It implies that the perceptual bias among those viewing bar charts in

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no order is likely to be higher than the bias among those observing the bar in a given order. Viewers could spend less time decoding the visuals which were arranged using certain logic than those who viewed the visuals which were set using no precise order (Yang, et al., 2020). This means the visuals in a given order help reduce viewers' perceptual bias better than those in a random order.

Finally, our experiment has verified that viewers' perceptual bias when reading charts with all bars of the same thickness was significantly less than the bias when observing charts with all bars of varying thickness. Like the two display features reported earlier, this finding is in line with past research. Based on Okan, et al. (2018), the finding in which the same bar thickness caused less bias than the varying thickness was due to the Gestalt principles. Viewers would better understand visuals if they were arranged uniformly rather than if their arrangement was peculiar. Similar findings can be found in Riedel, et al. (2022).

Our unique contributions to the field of visualization come from our findings in which (1) the interaction of the bar-ordering formats and the scaling styles and (2) that of the bar ordering formats and the bar width patterns on viewers' perceptual bias are confirmed significant (see Table 2). Once the vertical bars were in ascending order, the bias from those who read the finely- and the roughly- scaled bars was about the same. In addition, so was the bias from those who read the charts with all bars being of the same and those with all bars being of the different width. However, if bars were arranged in no particular order, the bias from those observing the roughly scaled bars was significantly higher than that from those reading the finely scaled ones. In addition, the bar arrangement in no particular order caused significantly higher perceptual bias among those who viewed the bars of varying width than among those who observed the bars of equal width. In fact, a close look at Tables 3 and 4 shows that the bias was noticeably higher when the charts were in random order with either rough scaling or different thickness of the bars.

The insignificance of the other interactions warrants two additional discussions. First, while the scaling styles and the bar width patterns each has a significant effect on viewers' perceptual bias, their interaction was not. Once the bar ordering format was out of the picture, we could thus assume their substantial effects were canceled out, so it became marginal. Second, the insignificant interaction of all three display factors on perceptual bias may suggest the unique importance of the bar ordering formats. Our implication comes from the fact that each of the three display features included in the current study has significant main effects on the perceptual bias but only when the bar ordering was included was its interactions with the other two features significant. Given that our project may be the first attempt to examine all three of them in one visualization experiment, we must wait for replicated projects to verify our implications. Further recommendations for various stakeholders are in the conclusion section.

Conclusion

Our experimental research offers empirical evidence on bar chart display design techniques that could hinder or promote viewers' perceptual bias in a business setting. We discovered that the bar arrangement in a certain order could be a crucial factor that promotes perceptual bias among viewers, as compared to the bar width patterns and the scaling styles of the Y-axis. This could be a result of its significant interaction with the patterns and the styles on the bias. Moreover, the main effects of all three features on the bias were also significant. Our findings have extended conceptual insights into business visualization. The understanding decoded from bar charts could be twisted using simple display designs of scaling and bar layout.

Our findings also offer two key practical contributions. The first guideline is for visual viewers. Learning about visual perception in the bar chart context, viewers should be fully aware of how their mind could be deceived through the coarsely scaled or through irregularly thick bar charts where all bars are in a random order. When noticing such a design of the display, the viewers must be quite attentive to what they are visualizing and make an effort to verify the content of the chart. The second recommendation is for visual makers. Should visual makers be bound by their job responsibility to persuade viewers through their design based on visual deception, they must be aware that viewers' perceptual bias could be twisted unless the

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charts are finely scaled, and all bars are in certain order. The visual makers should note that such display designs were proved in our experiment to hinder their perceptual bias.

Our study has a few limitations. The undergraduates who participated in our experiment were mostly seniors. In addition, based on our observation during the data collection, most of the subjects used their mobiles to participate in our research. Although mobiles are relatively popular compared to other means of communication, other access channels such as those through desktops were not included in the current study. These two limitations fairly limit the generalization of the study, thereby suggesting future research to address them.

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