Int. J. Anal. Appl. (2025), 23:85

International Journal of Analysis and Applications

Perceptual Bias in Mobile Radar Chart Visualization: Untangling the Effects of Radial Axes, Data Series, and Screen Refresh

Saranya Kantabutra[1], Chatpong Tangmanee[2,*]

[1]*Department of Management and Entrepreneurship, Chiang Mai University Business School, Chiang Mai University, Chiang Mai 50200, Thailand*

[2]*Department of Statistics, Chulalongkorn Business School, Chulalongkorn University, Bangkok 10330, Thailand*

**Corresponding author:* chatpong@cbs.chula.ac.th

ABSTRACT. While radar charts are widely used for visualizing multivariate data across various fields, and mobile technology enables screen refresh for potentially enhanced viewing experiences, the impact of chart design and user interaction on visual perception remains largely unexplored. This study investigates the effects of radial axes, data series, and screen refresh on perceptual bias in mobile radar chart visualization. An experiment with 157 participants revealed non-significant main effects for all three factors but significant interactions between data series and both radial axes and screen refresh. These findings extend the theoretical understanding of radar chart visualization bias and offer practical implications for both chart creators and viewers.

1. INTRODUCTION

Known as a spider chart or a star plot, a radar chart is a powerful visualization tool that allows for the representation of multivariate data in a two-dimensional space. The unique structure, which consists of a data series of radial axes emanating from a central point, enables viewers to compare multiple variables simultaneously. Together with a mobile screen refresh feature, the radar charts are useful in various fields, including business, healthcare, and education, where complex data sets need to be analyzed and communicated effectively.

The radar chart in Figure 1 presents six personality dimensions of four employees, where the dimensions exemplify the data presented on the radial axes, and the number of employees denotes that of the data series. Viewers should be able to compare four employees on their six

Received Feb. 25, 2025

2020 Mathematics Subject Classification. 91E30, 62P25.

Key words and phrases. perceptual bias; mobile radar chart visualization; radial axes; data series; screen refresh.

https://doi.org/10.28924/2291-8639-23-2025-85

ISSN: 2291-8639

personality dimensions. For instance, Rob scored four while Frank attained three on the positiveness dimension of personality. Also, Peter and Rob have the same scores of four on the openness dimension, while the highest and the lowest scores belong to Frank and Vic, respectively.

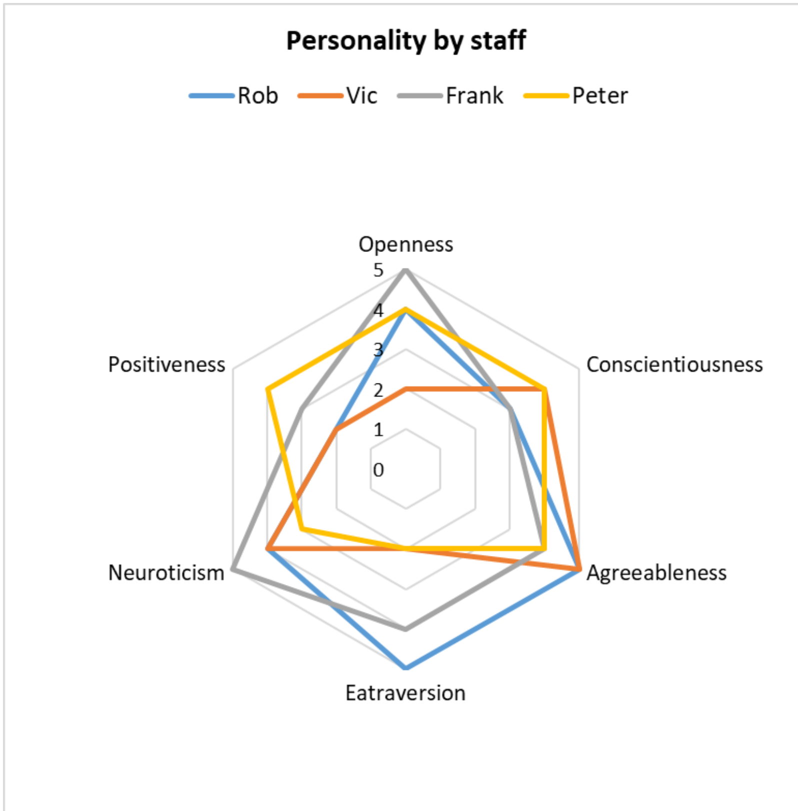

Figure 1. Example of a radar chart which uses six radial axes to display personality dimensions of four employees known as the data series. (Source: Author's work).

Such comparison in radar chart visualization may inevitably lead to perceptual bias, resulting from viewers' perception skills. Visual creators often include multiple radial axes (e.g., the personality dimensions in Figure 1), together with the number of data series (e.g., the number of employees in Figure 1) so viewers can have multiple comparisons to achieve a greater understanding of the chart. However, the viewers could incorrectly interpret the contents, resulting in their perceptual bias. This bias is the notion of individual differences in observing an object that comes to his or her attention, and it can later lead to various levels of understanding or misunderstanding. The nature of perceptual bias suggests that visualizations may be interpreted differently by different viewers, leading to varied conclusions based on the same visual. This notion generally implies negativity. In the visualization context, the perceptual bias always leads to misinterpretation of the data encoded in a chart [1]. Nonetheless, the perceptual bias does have positive connotations. One important advantage of the radar chart is that it simplifies complex information, allowing effective comparisons among multiple discrete variables across several series of data.

Numerous studies in the past have shed light on factors that could promote or hinder viewers' perceptual bias while observing visuals, including radar charts. Two of the chart design characteristics are particularly of interest: the number of radial axes and that of data series. These two variables were selected because the radar charts could, in general, accommodate comparisons among multiple radial axes or several data series. Yet, there is virtually no empirical evidence suggesting the optimal range of the number of radial axes or that of data series in one radar chart that could minimize the bias.

In addition to the two design characteristics, whether viewers refreshed the display screen on which radar charts reside may have an impact on the bias. An abundance of previous work has attempted to examine which chart characteristics could lower viewers' visualization bias [2, 3]. However, little attention has been given to viewers' interaction with display devices (i.e., zooming or screen refreshing) in order to eliminate visualization inaccuracy. In addition, there is no empirical research to verify experts' remarks [4, 5] in which interaction can reduce bias, thereby increasing viewers' chart comprehension. As such, the screen refresh was included as the final independent factor in our study. Our main purpose of research is, therefore, to test if the effects of radial axes, data series, and screen refresh on radar chart viewers' perceptual bias are significant.

2. LITERATURE REVIEW

Radar charts have gained significant traction in many sectors as a versatile tool for visualizing complex and multidimensional data. Their structure allows for the simultaneous comparison of multiple variables, making them particularly useful in performance evaluation, strategic planning, and decision-making processes.

One of the primary applications of radar charts in business is in the evaluation of key performance indicators (KPIs). Radar charts provide a visual representation of these indicators, allowing stakeholders to quickly identify strengths and weaknesses across different dimensions. Gilsing et al. [6] emphasized the importance of defining KPIs in business model evaluation, where radar charts can effectively structure performance assessments and aid in strategic decision-making. This visual approach not only simplifies the interpretation of complex data but also fosters a more collaborative environment for discussing performance metrics.

Additionally, radar charts can enhance communication within organizations by providing a common visual language for discussing complex data. Thaker et al. [7] highlighted the effectiveness of radar charts in communicating value frameworks in healthcare, suggesting that similar approaches could be beneficial in many situations. By standardizing the way performance and outcome metrics are presented, radar charts can facilitate clearer discussions among stakeholders, leading to more cohesive decision-making processes. Experts have pointed out that radar charts can become cluttered, potentially leading to viewers' perceptual bias. Therefore, it is essential to carefully select what will display on a radar chart to ensure clarity and effectiveness in communication [1, 8].

The radar charts consist of multiple radial axes radiating from a central point. One axis can accommodate a series of data. As such, a radar chart represents the complex structure of constructs, allowing multivariate visual inspection. This capability to represent multiple dimensions simultaneously is one of the primary strengths of radar charts, enabling stakeholders to visualize complex data sets in a straightforward manner. Despite their advantages, radar charts also have limitations. One common criticism is that radar charts can be difficult to interpret when too many series of data are on disproportionate radial axes. This can lead to viewers' confusion and perceptual bias. Therefore, it is essential to optimize the number of radial axes or that of data series to a manageable number in order to maintain clarity and effectiveness. Additionally, viewers should be cautious about the potential for misrepresentation of data, particularly if the scales are not uniform or if the radar profiles are not clearly labeled [9].

The common goal of creating a visual is that viewers comprehend all encoded data in the charts with no bias. Research has shown that human visual perception is not always adept at accurately interpreting the area or angles represented in a chart. For instance, Chiang et al. [10] highlighted that radar charts can effectively visualize complex data, but they may lead to a misunderstanding if viewers are not trained to understand the nuances of the graphical representation. This aligns with findings from Oigawa et al. [2], who recommended that radar charts be used alongside other visualization methods to enhance clarity and reduce the risk of perceptual bias. The combination of radar charts with line plots can provide a more comprehensive view of the data, thereby mitigating perceptual biases [10]. An improved design of radar charts could enhance the clarity of the encoded information, making it easier for users to draw accurate conclusions.

Perceptual bias in visualizations is often known as having significant negative implications for data interpretation. It can direct misinterpretations of the presented data, affecting the quality of insights derived from the visualizations. According to Zeljko et al. [1], the bias in multisensory perception can influence how viewers perceive the relationships among different data series. When multiple series are plotted on a radar chart, viewers may focus on the overall shape rather than the individual values, leading to an oversimplified understanding of the details. This can result in erroneous conclusions, particularly when the differences between data series are subtle. As noted by Sui et al. [11], perceptual processing can be affected by visual variables such as shape. If radar charts are not designed with careful consideration of these factors, they may lead to bias and ultimately to misleading interpretations. Viewers may be drawn to visually salient features that do not accurately represent the underlying data, resulting in poor decision-making.

Nevertheless, the perceptual bias in visualizations, including radar charts, could yield positive implications that enhance data interpretation. While often viewed negatively, it can also persuade viewers to agree to what graph makers imply via a chart. One significant positive implication of perceptual bias is the ability to streamline complex information. Radar charts are inherently designed to present multivariate data in a compact and visually intuitive format. Based on Cui and Liu's [8] work, the use of radar charts can effectively convey summary statistics, allowing viewers to quickly discern relationships between multiple variables. Another positive aspect of the perceptual bias in radar charts is its potential to facilitate comparative analysis. Radar charts allow for easy comparison between multiple entities or series of data [9]. Viewers can quickly assess how different categories perform relative to one another, leveraging their perceptual biases to make rapid judgments about performance.

The perceptual bias in radar chart visualization depends on two major factors: chart design features and viewer interaction attributes. The design features of radar charts that could hinder or promote viewers' perceptual bias include the number of radial axes, data series, or radar shapes. Given its definition of multivariate visual inspection, radar chart creators tend to present various data series on multiple axes. The selection and arrangement of these axes can greatly influence the interpretation of the data. For instance, Porter and Niksiar [9] emphasize that the scaling, rotation, and selection of axes can assign a preference to specific properties, thereby affecting the analysis of performance comparisons among biological systems. This flexibility allows chart creators to tailor the visualization in order to highlight particular attributes of interest, making radar charts particularly useful, where multiple traits may need to be assessed simultaneously. Peng et al. [12] note that radar charts provide a stronger visual impact compared to traditional bar charts, making it easier to display and compare the characteristics of an object across various attributes. This is particularly beneficial in contexts where stakeholders need to quickly grasp complex information, such as in managerial discussions about business outcomes [7]. The ability to visually represent multiple dimensions simultaneously helps in identifying patterns and making informed decisions.

According to Leary et al. [13], while radar charts can effectively display composite measures, the number of axes should be limited to avoid clutter and confusion. They recommend that a maximum of six to eight axes is optimal for ensuring that the chart remains interpretable and visually appealing. This aligns with findings from Wang and Li [14] who emphasize that the arrangement and number of axes in a radar chart can affect evaluation results, as the included angles between adjacent axes are equal, which may not accurately reflect the influence of each index on the evaluation object. Moreover, Dintzner et al. [15] illustrate the practical application of radar charts in educational assessments, where they effectively used a limited number of axes to represent core competencies, thereby making patterns and trends readily apparent. This practical example underscores the importance of optimizing the number of radial axes to reduce perceptual bias and facilitate understanding among stakeholders.

Regarding the data series in radar charts, Kalonia et al. [16] highlight the use of radar charts in visualizing complex data sets, specifically in the pharmaceutical domain. Their research demonstrates how radar charts can effectively represent the effects of various formulation variables on particle formation, thereby facilitating comparisons across multiple analytical techniques. This study underscores the potential of radar charts to convey intricate relationships among data series, yet it does not delve into the bias that may arise when users interpret these visualizations, particularly as the number of series increases. The work of Peng et al. [12] on radar charts for performance evaluation further presents the complexities involved in visualizing multidimensional data. They argue that while radar charts simplify the representation of complex relationships, the potential for perceptual bias increases with the number of dimensions presented. This highlights the necessity for scholars and practitioners to be aware of how bias can influence the interpretation of radar charts, particularly in high-dimensional contexts. Oehrig et al. [3] further contribute to this discourse by applying radar charts to environmental assessments, specifically analyzing the impact of a dam breach on water quality. Their findings suggest that while radar charts can aggregate complex data effectively, the number of data series can influence the interpretation of these visualizations. As the number of series increases, viewers may experience cognitive overload, leading to potential misinterpretations of the data. This phenomenon aligns with cognitive load theory, which posits that excessive information can hinder effective decision-making and comprehension. In a related study, Millecamp et al. [17] investigated the effectiveness of radar charts in user evaluations of Spotify recommendations. Their findings indicate that the radar chart format aids in decision-making, yet the number of data series presented can lead to varying levels of viewer comprehension. This suggests that while radar charts can enhance understanding, the perceptual bias associated with interpreting multiple series must be addressed to optimize their effectiveness.

In addition to the radar chart's design features, how viewers interact with display devices (e.g., screen refreshing or zooming) could have an impact on their perceptual bias of charts. In the context of interactive visualizations, Hernandez-Bocanegra's [18] research indicates that the presentation style of data can influence user satisfaction and decision-making speed. Although the study does not directly address screen refreshing, it implies that the immediacy of visual feedback—potentially enhanced by frequent refreshes—can facilitate quicker and more intuitive chart comprehension. This is inconsistent with the notion that viewers may feel compelled to refresh their displays to gain a better view of the charts or to obtain the most current data for analysis. Coleman et al. [4] explored electronic health record (HER) navigation patterns among physicians, noting that the design and refresh rates of screens can impact workflow efficiency. They suggest that understanding these interactions can inform the development of visualization dashboards that enhance critical care environments. This implies that frequent screen refreshes may be necessary to keep the data current, thereby reducing perceptual bias and improving the decision-making process in high-stake settings.

Moreover, the findings from Nolan et al. [19] regarding the usability of electronic health records highlight the necessity of understanding viewer interactions with electronic charts. They found that inadequate research on clinician-EHR interactions could lead to suboptimal designs that fail to account for the need for timely updates and refreshes, which are crucial in fast-paced medical environments [19]. This further supports the idea that users are likely to refresh their displays to ensure they are viewing the best information.

In summary, while plenty of previous work has addressed factors affecting perceptual bias or misunderstanding in data visualization [1, 20], little attention has been given to examine similar factors in the mobile radar chart context [2, 12]. Furthermore, the majority of these few research projects have concentrated on the chart design characteristics [3, 9, 14, 17] and overlooked the viewer's interaction with the charts. Based on the literature review, we may be one of the pioneers in blending the design features and the interaction attribute of a radar chart in a study of viewer perception and test if the effects of the two design features of radar charts and one interaction choice (i.e., viewer's screen refresh) on their perceptual bias are significant.

3. RESEARCH METHODOLOGY

To answer the research objectives, we discussed four methodology issues in this section: research approach, radar chart content and variable operationalization, experimental execution, and data analysis and hypothesis testing.

3.1 Research approach

To test the effects of radial axes, data series, and screen refresh on viewers' perceptual bias, an experiment was our research choice. We manipulated three independent factors, managed other variables, and observed their effects on viewers' bias in visualizing radar charts. According to Babbie [23], if there is an observed effect, it must be reliable and valid.

3.2 Chart content and Variable operationalization

To conduct a proper experiment and ensure the valid effects of the three independent variables on viewers' perceptual bias, it was important that (1) the radar chart contents with the radial axes and the data series and (2) the execution of the screen refresh had to be comparable.

The chart contents in our research were from the lifestyle survey among Asians [21]. We chose these contents because the details were neutral and appeared suitable for our experimental units, which were graduate students in a business school in Thailand.

The chart content on lifestyles among Asian people allows us to manipulate the display of various data series on multiple radial axes in our experimental radar charts. In the current research, we presented the lifestyle statements on the radial axes and selected the countries in which the residents have responded to the categories of the lifestyle statements as the data series. Once we chose the design variables for the radial axes and the data series, we had to decide what the values of each variable should be.

It has been known that a radar chart can accommodate multiple radial axes, allowing several comparisons of different values of the same construct across a common scale. Yet, it is still challenging to set the optimal number of these axes. Based on experimental work [12, 13], we chose five and eight lifestyle statements for the two values of the radial axes. These two values were selected following Leary et al.'s [13] recommendation, in which it is the optimal range for radial axes that the radar chart is still interpretable and aesthetically pleasing. The five lifestyle statements are (1) we monitor food before a meal to control weight, (2) we refuse vegetarian dishes, (3) the nutrition of what we eat is noted, (4) we look for healthy ingredients, and (5) we eat snacks between meals. The other three statements that were added to these five to form the choice of eight are (1) we are always on a diet, (2) we keep track of calories in a meal, and (3) when we eat depends on our schedule.

Similar to the radial axes, there is virtually no empirical work recommending the optimal number of the data series. Yet, Oehrig et al. [3] remarked with no empirical evidence that the greater the number, the more cognitive load the viewers must bear. We thus followed Albo et al. [22] and chose two and six for the possible values of the number of data series in the current research. Since the main purpose of using a radar chart is for comparison, the minimum value of the two was thus our first choice. Given no previous work suggesting the highest number of data series, we intuitively selected the choice of six for the second choice. Our radar chart in the current research, therefore, contains the data of Thai and Indonesian people for the series of two, and the additional four countries (i.e., Malaysia, Philippines, Singapore, and Vietnam) were added to form the data series of six.

In addition to the two design features, the third factor that we added to test if the effects of all three drivers on viewers' perceptual bias were significant was screen refresh. Specifically, it is referred to as whether viewers refreshed their screens while visualizing radar charts. This variable came to us based on our own observation in which viewers refresh their display screens in order to gain a better view of the visual. The screen refresh may subsequently reduce their perceptual bias. In our study, we treated this variable as a binary of whether viewers refreshed their screens. According to previous research on viewer interaction [18], we expect that the addition of this third factor to the two design features (i.e., the radial axes and the data series) will shed new light on explaining the viewer's perceptual bias.

Our dependent variable is viewers' perceptual bias. We developed eight multiple-choice questions to ask viewers while visualizing the radar charts. These questions ask how viewers interpret or perceive the chart in detail. Such interpretations include observing a specific value (e.g., what is the percentage of Thai respondents who look for healthy meals?) or comparing two proportions (e.g., what is the lifestyle the highest proportion of Thai respondents claimed to have?). We did not 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 respond to the items without a cognitive effort. We pretested these eight items with two faculty members, one staff member, and two graduate students in a business school, after which the items seem to properly capture viewers' perceptual bias. Given the eight items measuring perceptual bias, the maximum and the minimum scores of this perceptual bias are eight and zero, respectively. Readers should note that all eight items are available upon request to the corresponding author.

3.3 Experiment Execution

Four radar charts of identical contents were developed based on the two design features (i.e., two groups (5 vs 8) of radial axes and two (2 vs 6) series of data). The radial axes depicted various lifestyle statements, and the data series presents multiple countries from which the residents had responded to the lifestyle survey. The charts were created using Excel, which is part of Microsoft Office (Version 20h2). We used many defaults in Excel, so research replication would be possible. After the charts were ready, we developed a website that had distinctive links to them. The links were sent along with a call for research participation to the subjects who are Master's students in a business school. Hence, it is reasonable to claim that all participating viewers had comparable backgrounds and skills to participate in our experiment. Once the subjects agreed to take part in the research and clicked on the links, they would see the radar charts, the instructions on how to respond to it, along with the eight items measuring their perceptual bias. The order of the eight items was shown to each subject at random, thereby minimizing the effect of the item order. In addition, the subjects were asked to respond to whether they are color-blind and the other general demographic questions. The color blindness item was included since the insight the color-blind gain may be different from that the others observe. We also embedded a script in the host website to ensure the mobile visualization of the radar charts.

To record whether a subject had refreshed the display screen, we included a programming script in the host website. We tested all scripts several times following software engineering guidelines to ensure the record of the screen refresh was correct.

Figure 2 shows the radar chart for the two countries (i.e., two data series including Thailand and Indonesia), of which the residents reported their opinions on five lifestyle statements (five conditions of the radial axes). Figure 3 shows the chart for the six countries (i.e., six data series including Malaysia, the Philippines, Singapore, Vietnam, Thailand, and Indonesia) whose residents rated their opinions on eight lifestyle statements (eight conditions of the radial axes). In reference to Figures 2 and 3, there are three additional issues of the experiment execution. First, the actual chart details had to be in Thai for all participants to be Thai. Second, subjects had a total of 15 minutes to respond to all questions. The subjects would notice the timer on their screen's top right corner (not shown on these Figures), which would assist them in working on the experimental tasks wisely. Finally, while the subjects were responding to all eight items, the radar chart was kept constantly on the top half of the display, so they were able to view it until the final items were finished. This would mitigate the cognitive issue that the subjects had to remember the chart while answering the questions.

3.4 Data analysis and Hypothesis testing

We reported descriptive statistics of major variables. We also used the analysis of variance (ANOVA) to test if the effects of all three independent variables on the viewers' perceptual bias were significant.

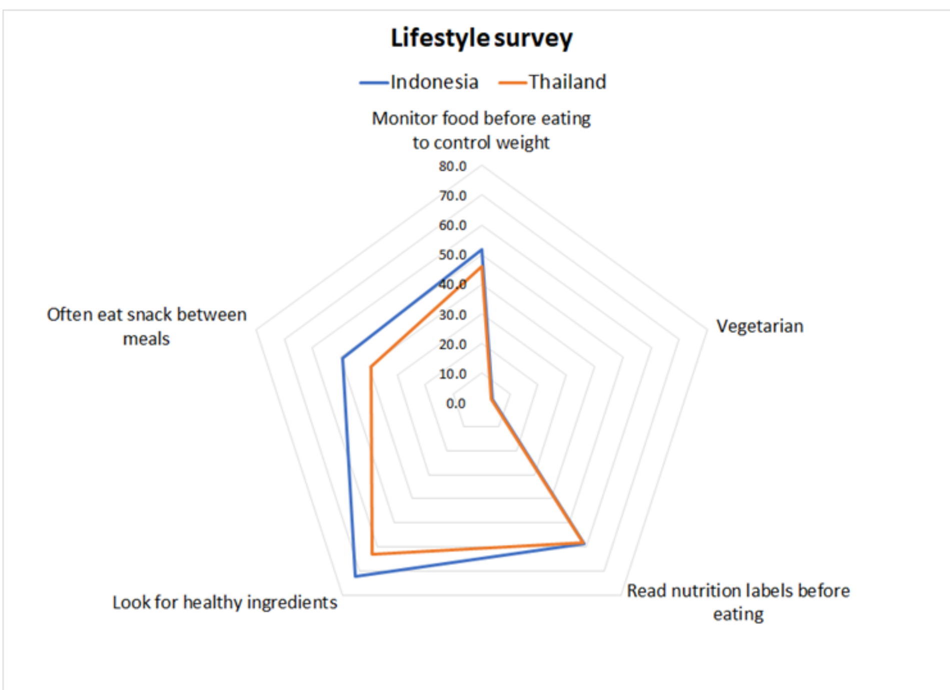

Figure 2. An example of the experimental radar chart with the data series of two and the radial axes of five. (Source: Author's work).

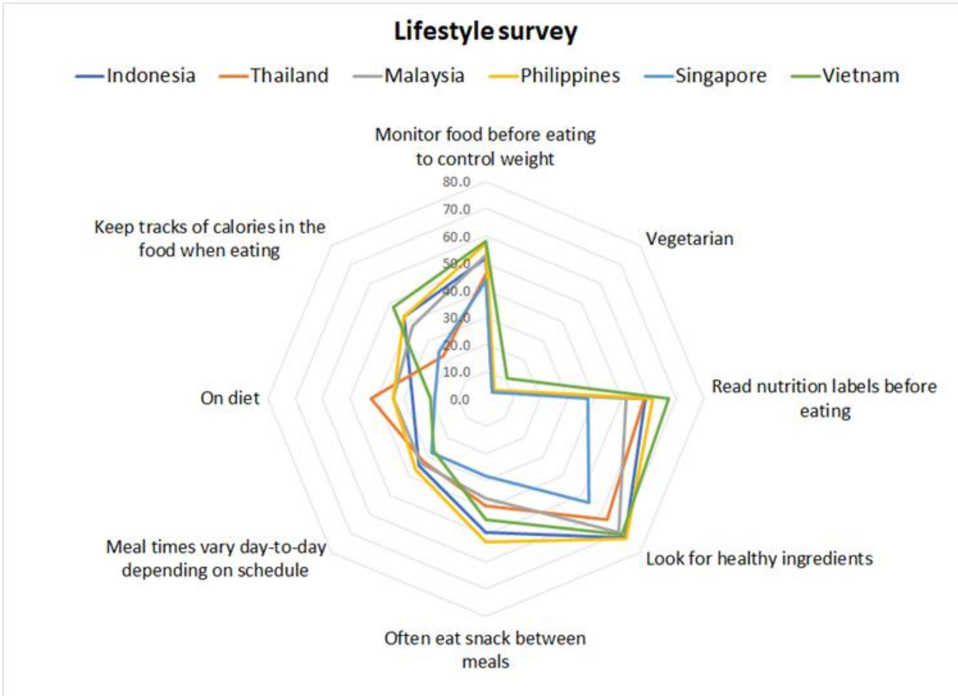

Figure 3. An example of the experimental radar chart with the data series of six and the radial axes of eight. (Source: Author's work).

4. RESULTS

From February to May 2022, 157 subjects took part in the experiment. We discovered no color-blind participants, all of whom used smartphones to finish the tasks. Based on the two groups of our experiment (two data series (i.e., countries (2 vs 6) in our research x two sets of data axes (i.e., lifestyle statements (5 vs 8)), the 157 subjects were adequate [23]. The highest percentage (60%) of the subjects were aged between 26 and 34 years old, and the same proportion were female. About 2 in 3 had an academic background in social science and management, and the rest were in health science or engineering.

Table 1 contains descriptive statistics of perceptual bias as classified by the three independent factors. In total, the participating viewers had, on average, a perceptual bias of 3.21 from the possible range of 0 to 8. Given its value of less than 4, it is reasonable to state that their bias was not too high. A look at the average of perceptual bias across values of the three independent factors in Table 1 shows that all but those between whether or not the screen refresh was invoked were about the same. Since the absolute values of the skewness and the kurtosis statistics in Table 1 are roughly less than one, the perceptual bias in the current research was normally distributed [24]. The parametric comparison of means (e.g., ANOVA) could be used, and the outcomes are in Table 2.

Table 1. Descriptive statistics of participating viewers' perceptual bias classified by the three independent variables

Variables	Count	Average	Standard Deviation	Skewness	Kurtosis
Number of radial axes					
5	78	3.19	2.815	0.641	-1.065
8	79	3.23	3.029	0.557	-1.291
Number of data series					
2	64	3.28	2.792	0.500	-1.138
6	93	3.16	3.012	0.654	-1.207
Whether viewers refreshed displays					
No	110	3.53	2.914	.458	-1.328
Yes	47	2.47	2.812	1.01	-0.477
Total	157	3.21	2.916	0.591	-1.185

Table 2. ANOVA results

Source of variance (SOV)	Sum square error (SSE)	df	Mean square error (MSE)	F statistics	p-value
Number of radial axes	7.565	1	7.565	.950	.331
Number of data series	10.355	1	10.355	1.300	.256
Screen refresh	13.066	1	13.066	1.641	.202
Numbers of radial axes x Number of data series	39.438	1	39.438	4.953	.028
Number of radial axes x Screen refresh	15.432	1	15.432	1.938	.166
Number of data series x Screen refresh	42.689	1	42.689	5.361	.022
Number of radial axes x Number of data series x Screen refresh	1.019	1	1.019	.128	.721
Error	1,186.40	149	7.962		
Total	1,315.17	156			

The analytic outcome in Table 2 confirmed (1) the main effects of all three factors on viewers' perceptual bias were not significant, but (2) the interactions between the data series and the radial axes and that between the data series and the screen refresh were significant while the other interactions were not. Given the two significant interactions, we further performed the independent t-test across (1) the radial axes and (2) those of whether the screen refresh was invoked for a given value of the data series, and the outcomes are in Tables 3 and 4, respectively.

For the data series of two, the difference of perceptual bias between the two values of radial axes was marginally significant, but for the data series of six, it was not. In contrast, the same difference between two values of the screen refresh was not significant when the data series was two. However, it was significant when the data series was six. Further discussions are in the next section.

Table 3. Comparison of perceptual bias across the number of radial axes for a given value of data series

Number of data series	Number of radial axes		t-statistics (df)	P-value
	5	8		
2	2.636	3.968	-1.989 (62)	0.049
6	3.600	2.750	1.366 (91)	0.175

Table 4. Comparison of perceptual bias across whether screen refresh was invoked for a given value of data series

Number of data series	Invoked Screen refresh		t-statistics (df)	P-value
	No	Yes		
2	3.234	3.411	-0.223 (62)	0.824
6	3.746	1.933	2.960 (65.124)	0.004

5. DISCUSSION

Our experiment was able to recruit 157 participants to view radar charts with identical contents on mobile phones. No participants reported color blindness, and all were graduate students of a business school. This would confirm comparable backgrounds among the subjects, validating proper units for experimental research. In addition, about 67% had a background in social science, and the rest in engineering or health science. Approximately 3 in 5 were female and 26 to 34 years of age. Such a background would validate that our subjects fairly represent the general labor force in Thailand, who must visualize various visuals, including radar charts, in their typical work assignments [25].

In total, our subjects scored an average perceptual bias of 3.21 from a minimum of zero and a maximum of eight from visualizing our experimental radar charts. The relatively low amount of bias may signify (1) the subjects could understand the charts, or (2) the charts were so easy to understand that the viewers could comprehend them with little bias. Given the lack of empirical evidence in the past, we are unable to verify these two statements and must challenge other researchers to examine viewers' bias in a similar context.

The analytic results confirm that the main effects of the radial axes, the data series, and the screen refresh on viewers' bias were not significant. However, the interactions between the data series and both (1) the radial axes and (2) the screen refresh were significant. Given the common factor of the data series across these two significant interactions, there are two additional discussions. First, for the data series of two, the bias arose from 2.636 to 3.968 in Table 3 as the number of redial axes increased. That is, the more cluttered the chart, the more likely the perceptual bias is, resulting in the significant differences of these biases. However, the marginal significance of 0.049 may suggest that the bias could have been comparable had the charts not been densely cluttered or had the number of radial axes been less than eight. Referring to Leary, et al. [13], the new guideline of the number of radial axes in a radar chart based on our findings should be five to seven. This may be our unique contribution to the field of mobile radar chart visualization. Considering the screen refresh when the number of data series was two, the differences of bias between when the screen refresh feature was invoked and when it was not non-significant for the p-value of 0.824 in Table 4.

Second, for the data series of six, the bias dropped from 3.600 to 2.750 in Table 3. Yet, the difference was not significant. Given the data series of six and the radial axes of eight, this is our experimental condition where the radar charts became most cluttered. Nonetheless, the bias was dropped slightly as compared to when the charts were less cluttered (i.e., when the data series was six and the radial axes were five). This is consistent with Tangmanee and Jittirat [26], in which viewers paid higher attention to the bar charts when they were more cluttered or oddly scaled as compared to when it was evenly scaled or less cluttered. Nevertheless, the difference in the current research was not significant. Considering the screen refresh when the number of data series was six, the difference of bias when the screen was refreshed was significantly higher than when it was not. It would thus validate that when radar charts were dense with the number of data series of six, viewers would refresh the screen display to gain a better view with less perceptual bias than when they were less cluttered with the data series of two. This finding is additional empirical evidence to confirm the importance of the viewer's interaction with the display screen [5]. The screen refresh feature is empirically proved in our research to be critical when a radar chart is cluttered.

The other non-significant interactions warrant additional discussion. Since the interactions (1) between the radial axes and the screen refresh and (2) among these two variables and the data series were not significant, it is reasonable to claim that the effect of the radial axes on the perceptual bias was relatively less than that of the data series. In this current study, the data series were the countries in which the residents were surveyed on the lifestyle statements, which were presented along the radial axes. The display of multiple axes may clutter a radar chart to a lesser degree than the presentation of multiple data series. Yet, this is still our conjecture that awaits further empirical validation in the business setting of mobile radar chart visualization.

6. CONCLUSION

Our research provides empirical validation in which viewers' perceptual bias could be lowered if (1) the number of data series is between five and seven and (2) the devices allow viewers to refresh display screens. Our findings have theoretical contributions. We have extended insights into perceptual bias in the mobile radar chart visualization. Displayed with multiple data series, the radar charts on mobiles are inevitably cluttered and becoming worse with details on too many radial axes. Nevertheless, the data series of less than seven or the enabled screen refresh feature could help alleviate radar chart viewers' perceptual bias.

Our study also offers practical contributions to two stakeholders. First, radar chart creators must be attentive to the chart design when the details are on various series of data along with multiple radial axes since the chart on such a small screen as a mobile must be cluttered and difficult to read. One practical guideline from our findings for the creators is the data series' optimal range of five to seven. In addition, to lower viewers' perceptual bias, the radar chart makers must ensure that the interactions with mobiles, including the screen refresh, are available. Second, radar chart viewers should be cautious when encountering radar charts with multiple radial axes or various series of data. These design characteristics can clog up the chart, potentially increasing the perceptual bias. One possible tool the viewers must learn is to refresh display screens to gain a better view of the chart and subsequently lower the bias.

This research has a few limitations. Since the experiment was not in a laboratory, the lack of control on some factors (e.g., the size of the mobile screens, or whether subjects viewed the charts in daylight or nighttime) may contaminate the findings and weaken the conclusions. The other limitation came from the scope of this current study. Given that our subjects were graduate students in one business school who may represent those who will routinely be involved in radar charts, any conclusions on other groups of viewers, such as the elderly, may have to wait for subsequent research projects.

Conflicts of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] M. Zeljko, P.M. Grove, A. Kritikos, Implicit Expectation Modulates Multisensory Perception, Attention Percept. Psychophys. 84 (2022), 915–925. https://doi.org/10.3758/s13414-022-02460-z.

[2] H. Oigawa, Y. Musha, Y. Ishimine, et al. Visualizing and Evaluating Finger Movement Using Combined Acceleration and Contact-Force Sensors: A Proof-of-Concept Study, Sensors 21 (2021), 1918. https://doi.org/10.3390/s21051918.

[3] J. Oehrig, N. Kananizadeh, M. Wild, S. Rouhani, W. Odle, Applying Multivariate Techniques to Fingerprint Water Quality Impact of the Fundão Dam Breach within the Rio Doce Basin, Integr. Environ. Assess. Manag. 20 (2024), 133–147. https://doi.org/10.1002/ieam.4820.

[4] C. Coleman, D. Gotz, S. Eaker, E. James, T. Bice, S. Carson, S. Khairat, Analysing EHR Navigation Patterns and Digital Workflows among Physicians during ICU Pre-Rounds, Health Inf. Manag. J. 50 (2021), 107–117. https://doi.org/10.1177/1833358320920589.

[5] R. Spence, Information Visualization: An Introduction, Springer, 2021. https://doi.org/10.1007/978-3-319-07341-5.

[6] R. Gilsing, A. Wilbik, P. Grefen, et al. Defining Business Model Key Performance Indicators Using Intentional Linguistic Summaries, Softw. Syst. Model. 20 (2021), 965–996. https://doi.org/10.1007/s10270-021-00894-x.

[7] N.G. Thaker, T.N. Ali, M.E. Porter, T.W. Feeley, R.S. Kaplan, S.J. Frank, Communicating Value in Health Care Using Radar Charts: A Case Study of Prostate Cancer, J. Oncol. Pract. 12 (2016), 813–820. https://doi.org/10.1200/JOP.2016.011320.

[8] L. Cui, Z. Liu, Synergy between Research on Ensemble Perception, Data Visualization, and Statistics Education: A Tutorial Review, Attention, Percept. Psychophys. 83 (2021), 1290–1311. https://doi.org/10.3758/s13414-020-02212-x.

[9] M.M. Porter, P. Niksiar, Multidimensional Mechanics: Performance Mapping of Natural Biological Systems Using Permutated Radar Charts, PLOS ONE 13 (2018), e0204309. https://doi.org/10.1371/journal.pone.0204309.

[10] S. Chiang, R. Moss, A.P. Black, et al. Evaluation and Recommendations for Effective Data Visualization for Seizure Forecasting Algorithms, JAMIA Open 4 (2021), ooab009. https://doi.org/10.1093/jamiaopen/ooab009.

[11] J. Sui, E. Ohrling, G.W. Humphreys, Negative Mood Disrupts Self- and Reward-Biases in Perceptual Matching, Quart. J. Exp. Psychol. 69 (2016), 1438–1448. https://doi.org/10.1080/17470218.2015.1122069.

[12] W. Peng, Y. Li, Y. Fang, Y. Wu, Q. Li, Radar Chart for Estimation Performance Evaluation, IEEE Access 7 (2019), 113880–113888. https://doi.org/10.1109/ACCESS.2019.2933659.

[13] T. Leary, S. Ridley, K. Burchett, et al. Assessing Critical Care Unit Performance: A Global Measure Using Graphical Analysis, Anaesthesia 57 (2002), 751–755. https://doi.org/10.1046/j.1365-2044.2002.02692.x.

[14] Y.L. Wang, Y.J. Li, Comprehensive Evaluation of Power Transmission and Transformation Project Based on Improved Radar Chart, Adv. Mater. Res. 354–355 (2011), 1068–1072. https://doi.org/10.4028/www.scientific.net/AMR.354-355.1068.

[15] M.R. Dintzner, E.C. Nemec, K. Tanzer, B. Welch, Using Radar Plots for Curricular Mapping to Visualize Assessment in a New Doctor of Pharmacy Program, Amer. J. Pharm. Educ. 79 (2015), 121. https://doi.org/10.5688/ajpe798121.

[16] C. Kalonia, O.S. Kumru, J.H. Kim, et al. Radar Chart Array Analysis to Visualize Effects of Formulation Variables on IgG1 Particle Formation as Measured by Multiple Analytical Techniques, J. Pharm. Sci. 102 (2013), 4256–4267. https://doi.org/10.1002/jps.23738.

[17] M. Millecamp, N.N. Htun, Y. Jin, K. Verbert, Controlling Spotify Recommendations: Effects of Personal Characteristics on Music Recommender User Interfaces, in: Proceedings of the 26th Conference on User Modeling, Adaptation and Personalization, ACM, Singapore Singapore, 2018: pp. 101–109. https://doi.org/10.1145/3209219.3209223.

[18] D.C. Hernandez-Bocanegra, J. Ziegler, Effects of Interactivity and Presentation on Review-Based Explanations for Recommendations, arXiv:2105.11794 [cs.HC] (2021). https://doi.org/10.48550/ARXIV.2105.11794.

[19] M. Nolan, R. Siwani, H. Helmi, et al. Health IT Usability Focus Section: Data Use and Navigation Patterns among Medical ICU Clinicians during Electronic Chart Review, Appl. Clin. Inform. 08 (2017), 1117–1126. https://doi.org/10.4338/ACI-2017-06-RA-0110.

[20] C. Yan, Y. Chen, Y. Zhang, et al. Perceptual Scale Expansion: A Natural Design for Improving the Precision of Motor Control, Quart. J. Exp. Psychol. 76 (2023), 1481–1496. https://doi.org/10.1177/17470218221115075.

[21] Euromonitor, 2021. Lifestyles Survey of 2021. https://www.portal.euromonitor.com/portal/dashboard/index#/. Accessed on July 4, 2021.

[22] Y. Albo, J. Lanir, P. Bak, S. Rafaeli, Off the Radar: Comparative Evaluation of Radial Visualization Solutions for Composite Indicators, IEEE Trans. Vis. Comput. Graph. 22 (2016), 569–578. https://doi.org/10.1109/TVCG.2015.2467322.

[23] E. Babbie, The Basics of Social Research, Cengage Learning, Stamford, (2013).

[24] S. Muylle, R. Moenaert, M. Despontin, The Conceptualization and Empirical Validation of Web Site User Satisfaction, Inf. Manag. 41 (2004), 543–560. https://doi.org/10.1016/S0378-7206(03)00089-2.

[25] National Statistical Office, Population 15 Years and Over by Level of Educational Attainment, Sex and Province: 2022. https://www.nso.go.th/nsoweb/downloadFile/stat_impt/ic/file_xls_en. Accessed on Jan. 14, 2023.

[26] C. Tangmanee, P. Jittarat, Effects of Scale Orientations, Scale Formats, and Background Display Styles on Thai High School Students' Bar Graph Visualization, The International Journal of Business and Information 8 (2013), 229-246. https://doi.org/10.6702/ijbi.2013.8.2.3.