Searching for Extreme Portions in Distributions: A Comparison of Pie and Bar Charts

Frode Eika Sandnes[1,2][0000-0001-7781-748X], Aina Flønes[1], Wei-Ting Kao[1], Patrick Harrington[1] and Meisa Issa[1]

[1] Oslo Metropolitan University, N-0130 Oslo, Norway
[2] Kristiania University College, N-0153 Oslo, Norway
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frodes@oslomet.no,S305075@oslomet.no,S334005@oslomet.no,phaa@gmail.com,S333998@oslomet.no

Abstract. Aggregated data visualizations are often used by collaborative teams to gain a common understanding of a complex situations and issues. Pie and bar charts are both widely used for visualizing distributions. The study of pie versus bar charts has a long history and the results are seemingly inconclusive. Many report authors prefer pie charts while visualization theory often argues for bar graphs. Most of the studies that conclude in favor of pie charts have focused on how well they facilitate the identification of parts to the whole. This study set out to collect empirical evidence on which chart type that most rapidly and less erroneously facilitate the identification of extreme parts such as the minimum, or the maximum, when the distributions are similar, yet not identical. The results show that minimum values are identified in shorter time with bar charts compared to pie charts. Moreover, the extreme values are identified with fewer errors with bar charts compared to pie charts. One implication of this study is that bar charts are recommended in visualization situations where important decisions depend on rapidly identifying extreme values.

Keywords: visualization, distributions, extreme values, pie chart, bar chart, response time, error, perceived accuracy.

1 Introduction

Visualizations of aggregated data are often used by collaborative teams, such as leaders of large organizations, to understand complex situations, issues, and relationships. Graphical visualizations can be effective in communicating certain characteristics or draw attention towards particular issues. Perhaps the most common visualization types include the line graph, scatterplot, bar graph and pie chart. Line graphs and scatter plots are used to visualize the relationship between two variables, while bar charts and pie charts are typically used to visualize the distribution or portions of various categories of a whole. In many situations pie charts and bar charts may be used with similar effectiveness. In such situations it is the personal preferences of the authors that determine

This is a post-peer-review, pre-copyedit version of a conference proceeding published in CDVE: International Conference on Cooperative Design, Visualization and Engineering. CDVE 2020 Proceedings, that is part of the Lecture Notes in Computer Science book series.
The final authenticated version is available online at: https://doi.org/10.1007/978-3-030-60816-3_37

what visualization method to use. This is especially the case if the purpose of a visualization is to show that something is uneven or unbalanced. Some argue that the pie chart is more appealing, and research has also provided evidence that proportions are perceived in a shorter time with higher accuracy with pie charts compared to bar charts [1].

Visualizations can easily be generated with common tools such as Microsoft Excel, and consequently visualizations are often created by authors without any visualization training or expertise. In some situations, the choice of visualization technique is based on a belief that a particular visualization technique is superior to others. For instance, some argue that pie charts are more effective than bar charts because they can be used as a metaphor of dividing a cake, pie or pizza, while there are fewer obvious metaphors for bar charts. The renowned visualization expert Stephen Few writes “nothing that I teach is met with such fierce opposition as my low opinion of them. People cling to them aggressively” in his reading entitled “Our Irresistible Fascination with All Things Circular” [2]. Among visualization experts the strengths and weaknesses are well-understood, that is, that bar charts generally are more effective in situations where the portions are similar as it is easier to discriminate between different categories, while it is hard to distinguish between categories of similar but unequal size in pie charts [2]. This is because the human visual perception system has been shown to perform more accurately when determining length compared to determining area and angles.

Arguments in favor of pie charts include its ability to make part of a whole estimations easier than with bar charts. Pie charts also provide five easily recognizable anchors, namely 0%, 25%, 50%, 75% and 100% analogous to dial positions 0am, 3 am, 6 am and 9 am on a clock surface [3]. Pie charts are argued to be more attractive than bar charts. There are also situations where pie charts are not suitable such as visualizing small changes or how proportions change over time.

There is quite a long history of research into bar versus pie charts. Most of these studies have focused on assessing proportions of a whole and results have shown that pie charts are superior for this task [1]. However, in some situations the viewer may only be interested in determining the smallest or the largest portion. If important decisions are to be made on such information, it is crucial that the corresponding visualization results in the shortest possible response time with a low risk of erroneous assessments. This study therefore set out to explore how suited pie (see Fig. 1) and bar charts (see Fig. 2) are for supporting the identification of the extreme portions when the items are of similar, yet not identical, magnitude. Our hypotheses are that the bar chart leads to (a) more rapid identification of extreme portions and (b) fewer errors than pie charts.

The rest of this paper is organized as follows. Section 2 briefly review the related works on visualization. This is followed by a description of the methodology in Section 3, the results in Section 4 and discussion in Section 5. The paper closes with the conclusions in Section 6.

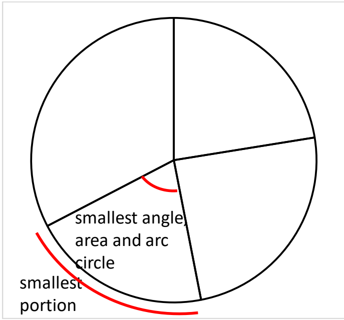


Fig. 1. Identifying the smallest item in a pie chart by locating the smallest angle, smallest area, smallest arc circle or a combination. Comparisons are difficult as items are not side-by-side.

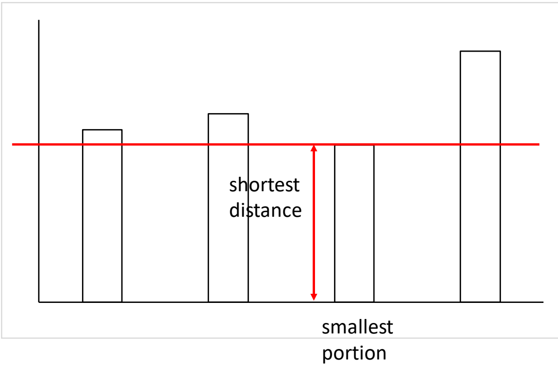


Fig. 2. Identifying the smallest item in a bar chart by locating the shortest distance (and/or smallest area). Comparison is easy as items are side-by-side.

2 Related work

The pie chart has been around for more than 200 years and its introduction is often attributed to William Playfair [4]. The pie chart is often referred to as a circular chart. An informative survey of research into pie charts by Spence [4] illustrated that there has been much disagreement regarding the effectiveness of pie charts and bar charts. More recent studies show that the pie chart results in shorter response times and lower errors compared to bar charts for tasks involving the assessment of portions as a whole where participants have been asked to visually estimate a portion in charts as a numeric integer percentage [1].

Although the just noticeable difference in angle perception has been found to be related to the actual angle in general [5], it has also been found that it is actually not the angle that is the most influential characteristic of a pie segment, but rather its area and arc length [6, 7]. It has also been found that proportion judgements are affected by bias as small proportions sometimes are overestimated and large portions are underestimated [8].

Other studies are making less informed claims about the power of pie charts such as their power to communicate issues of climate changes [9]. A totally different take of the pie chart is a study that demonstrated how pie charts can be used in the sonification of data were the pie chart is visualized with audio when the person turns his or her head in different directions [10].

Despite the research results that supports the use of pie charts, visualization experts in general appears quite cautious about circular visualization tools [2, 11]. The literature has mostly focused on more exotic circular diagrams such as radar diagram [12], petal charts [13] and polar plots [14]. There has also been research on bar charts addressing issues on how to represent large scales [15] or using diverging stacked bars for illustrating Likert responses [16]. Embellishments to strengthen visualizations is yet another technique that has received some attention [17].

3 Method

3.1 Experimental design

A controlled within-groups experimental design was selected with chart type as independent variable and task completion time, error rate and preference as dependent variables. The independent variable chart type had two levels, namely bar chart and pie chart.

3.2 Participants

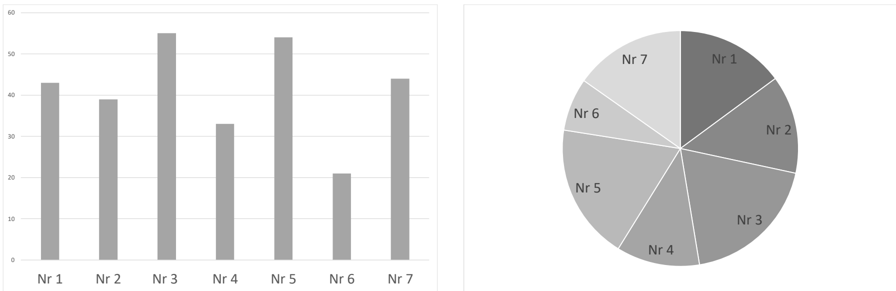
A total of 20 participants was recruited for the experiment of which 10 were female and 10 males. Their ages ranged from 20 to 56 years of age with a mean age of 33 years. None of the participants reported having any visual impairment. All the participants had completed secondary education and nine participants had completed higher education. Two of the participants reported a diagnosis of dyscalculia.

3.3 Materials

A total of 10 datasets were created and used to create 20 charts, that is 10 pie charts with 10 corresponding bar charts that were shuffled into random order. Each dataset comprised a set of different but similar numbers. These numbers were organized into a random order such that the corresponding chart had the bars and pie-slices in a non-decreasing or increasing order. Unnecessary visual elements were removed from the charts, such as text percentages and titles, to prevent diverting attention away from the task of assessing the portions. Each item was numbered for naming purposes.

The 10 datasets comprised of 3 to 14 data points ($M = 7.6$, $SD = 2.8$). The data points were randomly generated in different absolute ranges, although this was not intended to have any effect on the visual perception. The relative ranges were limited to making the portions appear close-to-similar. The mean normalized ranges in percentages of the datasets were ($M = 38.5\%$, $SD = 30.1\%$). The mean difference between the smallest item and the second smallest item was (M = 5.0%, SD = 6.1%). This measure can be considered an indicator of task difficulty.

All the charts were created with Microsoft Excel using shades of grey rather than color as different colors are believed to affect the perception of area [18]. Different levels of grey are also likely to affect the perception of area, but to a lesser degree. The differentiation with color is not needed with bar charts but may help with the differentiation of items. Each item had a unique shade of grey with a clear black outline. All bars had the same color. Each item was labelled. Fig. 3 shows an example of a pie and a corresponding bar chart used in the experiments. An additional five charts were generated as a control with a reversed order of the items.



(a) Bar chart (b) Pie chart

Fig. 3. A dataset with 7 items visualized as a bar chart and a pie chart. The task is to identify the smallest item, namely item 6.

3.4 Task

For each chart presented the participant had to identify and verbally report the number and/or point at the smallest item.

3.5 Procedure

The participants were tested individually in an isolated setting indoors. The total of 25 charts were shown using a PowerPoint presentation. Each participant viewed the charts in the same order, but the presentation order of the charts was randomized. The time to complete each task, that is, the time from when the chart was displayed until the oral response was given, was measured manually using a stopwatch as well as the correctness of the answer. At the end of the session the participants were asked to rate their perceived accuracy of both the pie and the bar charts using a scale from 1 to 10 where 10 represent most accurate and 1 least accurate.

No personal information was collected from the participants. The General Data Protection Regulations (GDPR) was adhered to and no data collection permits and approvals had to be solicited because the experiment was anonymous and did not involve any sensitive information. Participants had the opportunity to withdraw from the experiment at any time.

3.6 Analysis

For each person, the median time to interpret the pie and bar charts were determined for each participant, respectively. The data were analyzed using the open source statistical analysis software package JASP version 0.11.0.0 [19].

4 Results

4.1 Task completion time

A Shapiro Wilks test revealed that the median task completion times were not normally distributed ($W = 0.861$, $p = .008$). Therefore, the non-parametric Wilcoxon signed rank test was used to compare the task completion times of the two chart types. The test revealed that there was highly significant effect of chart type on task completion time ($W = 0.0$, $p < .001$). Fig. 4 shows that the mean completion time with the bar chart ($M = 2.24$, $SD = 0.48$) was nearly half that of the completion time with the pie charts ($M = 5.26$, $SD = 1.99$).

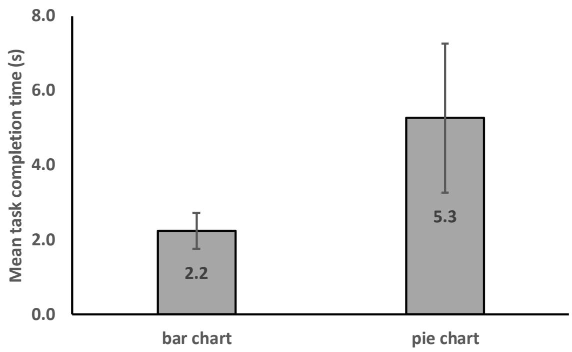


Fig. 4. The observed time to identify the smallest item in pie charts and bar charts. Error bars show standard deviation.

4.2 Error rate

Fig. 5 shows the error rates observed for the two visualization methods. A Wilcoxon signed rank test revealed that the error rates were significantly lower with bar chart compared to the pie charts ($W = 0.0$, $p < .001$). The mean error rate was only 1% ($M = 1.05$, $SD = 4.59$) with the bar chart, while it was a massive 51.1% with the pie chart ($M = 51.05$, $SD = 14.10$).

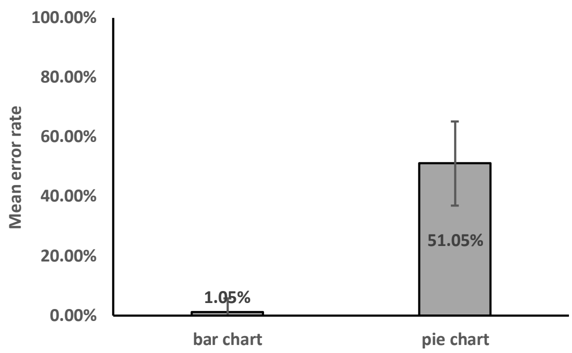


Fig. 5. The error rates observed with pie charts and bar charts. Error bars show standard deviation.

4.3 Perceived accuracy

Fig. 6 shows the perceived accuracies of the two visualization methods. A Wilcoxon signed rank test ($W = 190$, $p < .001$) revealed that the perceived accuracies were significantly higher with the bar chart ($M = 9.1$, $SD = 1.1$) than with the pie chart ($M = 5.3$, $SD = 1.3$).

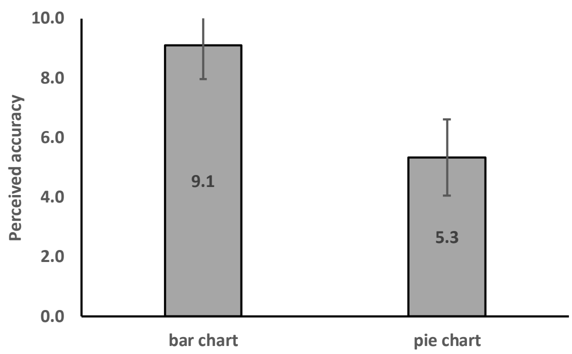


Fig. 6. The perceived accuracy of pie chart and bar charts. Error bars show standard deviation.

5 Discussion

The results support the hypothesis and the advice given in the visualization literature. It takes less time to locate the smallest item with the bar chart compared to the pie chart. Although not tested, one may expect that we would have gotten similar results if the task involved finding the largest number as well. Clearly, identifying the shortest bar is faster and easier than locating the pie slice with the smallest area and smallest angle. Bar chart comparisons are performed along one dimension, in this case the vertical dimension, while the pie chart comparisons need to be performed along two dimensions simultaneously.

The results show that the bar chart also resulted in nearly no errors, while errors are easily made with the pie chart suggesting that it is actually very hard to make accurate visual comparisons between pie chart items of similar magnitude.

The actual accuracy also matches the perceived accuracy as the participants subjective scoring of the two chart types as the bar chart obtained a nearly perfect score, while the pie chart was rated much lower in terms of accuracy.

The experiment was conducted under indirect time pressure. The participants were not instructed to conduct the task as quickly as possible but were informed that the task was timed. Consequently, most participants performed the task quickly. We argue that it is appropriate to test such visualization methods under time pressure to somewhat mimic real situations where decisions must be made quickly based on a rapid glance at a chart. It is therefore crucial that such the perceived impression is as correct as possible.

5.1 Limitations

The participants in this study represent a limited cohort in that all had completed secondary education. It would have been interesting to repeat the experiment also including a cohort of participants without secondary education and then assumedly less practice in interpreting charts.

The measurements were obtained manually, and small measurement inaccuracies may therefore have been introduced. More precise measurements would be possible if the experimental setup was implemented with automatic measurements, for instance based on registering when and if the participants pressed the right item on a touch display.

Usually pie charts make extensive use of colors, although effective use of colors becomes increasingly difficult with many items. The lack of color in the experiment may have made it less comparable to pie charts usually found in mainstream publications. Shades of grey was used to distinguish different pie chart items. These grayscales may have somehow affected the perception of the items for the pie chart. One alternative would be to use the same color for all the pie items, for example a white background, hence utilizing only the sector outline to indicate size.

Another potential shortcoming of the experiment was the inclusion of gridlines with the bar charts, while the pie charts did not have any support lines of any kind. However, it is uncertain if the gridlines are beneficial or not in identifying the smallest item. Moreover, it must be noted that only very weak gridlines were included, that is, the default gridlines included by Excel when making bar charts.

The participants were probed about how effective they found the two chart types after the experiments. In addition, it would also have been interesting to also probe the participants' preferences before the experimental task to test the assumption that many individuals believe pie to be better than bars. However, the actual presence of pie charts in various contexts is indeed evidence that pie charts are considered useful.

6 Conclusions

An experiment was conducted to assess how well bar and pie charts supports the search for extreme portions when these portions have similar size. The results quite clearly confirm the superiority of the bar chart in fast and correct identification of extreme portions compared to pie charts. The participants perceived accuracies are also consistent with the observed accuracies. Implications of these result is that bar charts should always be used if the task involves identifying extreme items and these items are of similar size. A generalization of this is that also any visualization with unknown data, i.e., automatically generated data should employ bar charts and not pie charts. However, it is important to select the visualization method according to purpose. For instance, if the goal is to illustrate imbalance or unequal quantities the pie chart may be used as well as a bar chart and if the goal is to determine parts of the whole a pie chart may be a more effective option.

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