How well do we read pie charts?

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Abstract

Pie charts are widely used but often criticized for their perceived inaccuracy in conveying categorical information. This study examined how accurately individuals estimate percentages in pie charts and whether accuracy differs by segment size or orientation. Thirty-one participants estimated highlighted segments in 20 pie charts. Results show that participants achieved a mean absolute error of 2.14%, indicating generally accurate performance. No significant differences were found between small and large segments, but orientation had a significant effect: values in bottom-oriented segments were underestimated, while top-oriented segments were overestimated. These findings suggest that pie charts can be interpreted with reasonable accuracy, though orientation biases warrant further investigation.

Introduction

Pie charts are among the most commonly used visualization techniques for representing part-to-whole relationships. Despite their popularity, their effectiveness has been widely debated. Critics argue that pie charts are inherently flawed because they rely on angle perception, a task humans perform poorly (Mackinlay, 1986) . Conversely, proponents suggest that pie charts can be effective under specific conditions, particularly when the number of segments is limited and design choices enhance readability (Hill, 2024; Skau & Kosara, 2016).

Previous research has examined various aspects of pie chart interpretation, including the accuracy of angle estimation and the influence of visual factors such as color and labeling. Studies by Skau and Kosara (2016) and Kosara (2019) indicate that visual cues other than angle may play a more significant role in interpretation. Furthermore, viewing time has been shown to affect accuracy: longer exposure improves estimation performance, whereas shorter viewing times (<8 seconds) reduce it (Schonlau & Peters, 2008).

The present study focuses on a specific and practical question: *How accurately can individuals estimate percentages in pie charts under controlled conditions?* To address this, we investigate the following research questions:

1. **First question:** How accurately can individuals estimate percentages in pie charts?
2. **Second question:** Do individuals differ significantly in their ability to estimate percentages in pie charts?

3. **Third question:** Does estimation accuracy differ based on segment size (small vs. large)?

4. **Fourth question:** Does estimation accuracy differ based on segment orientation (top vs. bottom)?

Unlike some prior studies that incorporate multiple visual factors, this research minimizes extraneous variables by using a high-contrast design and a fixed presentation format. By isolating these factors, we aim to provide clearer insights into the perceptual challenges associated with pie charts.

Methods

Participants

A total of 31 individuals participated in the study. Participants were recruited from a Microsoft Teams group of 116 members within the Data and AI department at Cegeka. Participation was voluntary.

All participants were aged 21 years or older and held roles related to data and artificial intelligence. None had specific expertise in data visualization, which helped minimize bias in estimation performance. Seven participants opted to remain anonymous by not providing an email address; consequently, they were not eligible for the incentive (a cinema ticket awarded to the most accurate participant).

Apparatus

The study was conducted using Microsoft Forms. The questions were distributed online. Participants completed the test using their own devices, including laptops, tablets, or mobile phones. No monitoring or restrictions were placed on device type or screen size.

This approach reflects the reality of modern data consumption, where professionals frequently access dashboards and visualizations across a variety of devices. Designing for multiple device types is increasingly important, as dashboards are often viewed on-the-go and must remain functional and readable regardless of screen size or orientation (Horak, Aigner, Brehmer, Joshi, & Tominski, 2021).

During the test, participants were shown one pie chart at a time. Below each chart, a text field was provided where they could enter their estimated percentage for the highlighted segment.

Stimuli

The stimuli used in this study consisted of 20 pie charts, each displaying one highlighted segment. These charts were generated using Python, with the code publicly available on GitHub (De Preter, 2025). A fixed random seed (`random.seed(4)`) was used to ensure reproducibility.

The pie charts were randomly generated but followed specific constraints unknown to participants. Specifically, the percentages were drawn from four groups of five values each, with the following distribution rules:

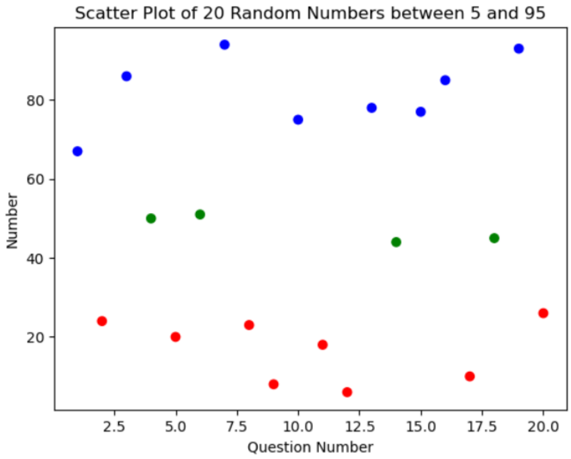

Figure 1. Percentages below 40%, labeled as 'small', are colored red. Percentages above 60%, considered 'large', are shown in blue. All other values are colored green.

- Two values between 5% and 40%
- Two values between 60% and 95%
- One value between 40% and 60%

Figure 1 presents the distribution of the percentages.

The orientation was analyzed only for segments with a percentage lower than 40%. Four graphs were classified under the "Top" category (see 2), and four under the "Bottom" category (see 3).

The highlighted segment was always rendered in dark gray, while the remaining segments were white. This high-contrast color scheme supports accessibility, including for

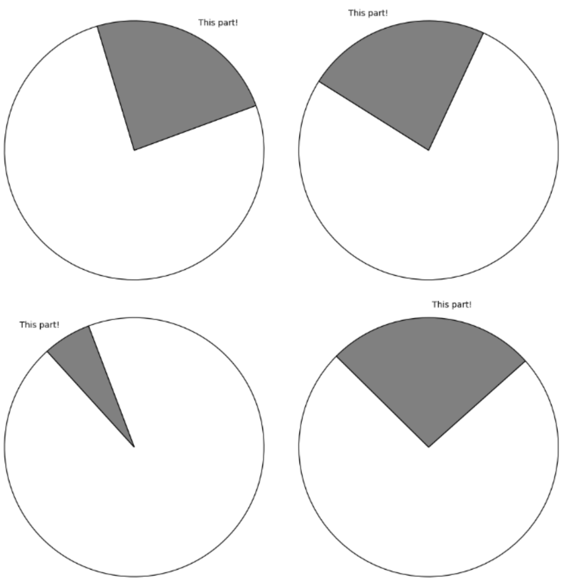

Figure 2. Four segments categorized as top.

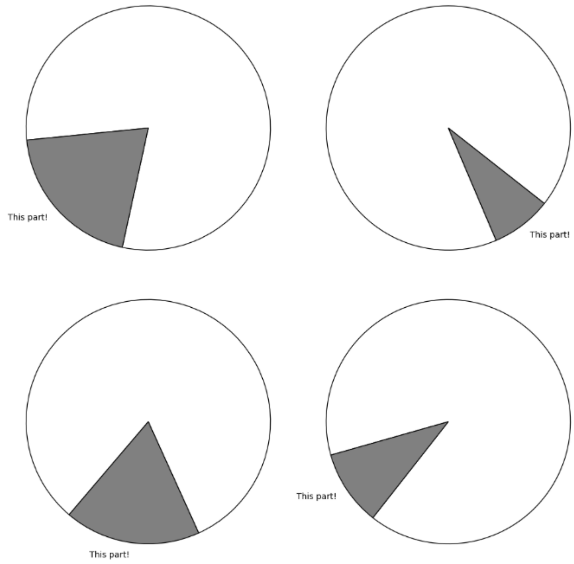

Figure 3. Four segments categorized as button.

individuals with color vision deficiencies.

Each chart included the label *"This part!"* pointing to the highlighted segment. Participants were shown one chart at a time, with a text field below to enter their estimated percentage.

Figure 4 illustrates an example question. At the top of the screen, participants could see their progress within the survey (e.g., *Question 1/20* in this example). At the bottom, a note was displayed in Dutch: *"Aantal moet tussen 1 en 100 liggen"* (translated: "The number must be between 1 and 100"). This message was automatically translated based on the browser's language settings.

Design

Participants accessed the study via a link to a Microsoft Form. All participants received the same pie charts in the same fixed order. The test consisted of 22 pie charts:

- The first 2 charts served as example questions.
- The remaining 20 charts formed the actual test.

The example charts featured segments of 50% and 25% and provided immediate feedback after each submission, showing the correct answer regardless of the participant's input. All subsequent questions did not provide feedback.

All questions were mandatory, except for the optional email address field. Participants could not go back to previous questions once submitted. A time limit of 10 minutes was enforced automatically by Microsoft Forms, and total duration was recorded. This time limit was continuously displayed at the top of the screen, as shown in Figure 4.

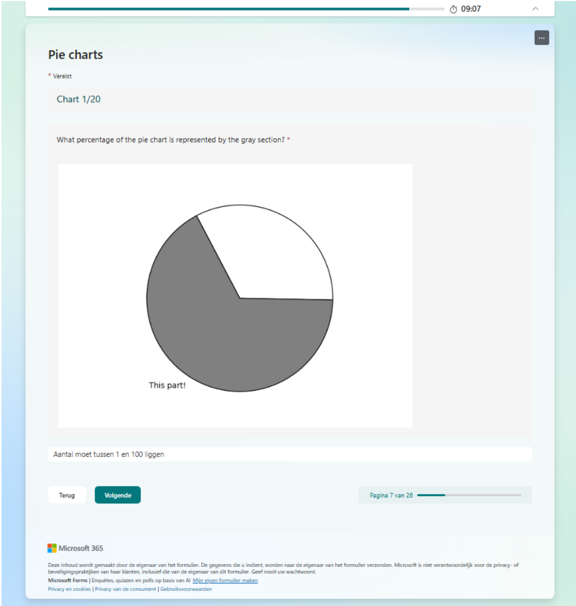

Figure 4. example of a question

Procedure

Participants in this study were colleagues from the Data and AI department at Cegeka. They were provided with a link to the Microsoft Form, which they accessed using their own devices (e.g., laptop, tablet, or mobile phone).

Upon clicking the link, participants were directed to the survey. The survey began with an informed consent form, which participants had to agree to before proceeding. They were then shown the following message:

"Enter your email address below to participate. If your estimate of the percentages is the most accurate, you'll win 1 cinema ticket. Your email will only be used to contact the winner and will not be used for any other purpose."

After entering their email address (or choosing to remain anonymous), participants received the following instructions:

"In this study, we're exploring how easy or difficult it is to estimate percentages from pie charts. You'll start with 2 example questions to get familiar with the task. After that, you'll be asked to estimate the percentages in 20 pie charts. The participant with the smallest total absolute error across all charts will win 1 cinema ticket!"

The survey started with two example pie charts to help participants understand the task. These examples included feedback on their estimations. After the examples, participants proceeded to the main task, which consisted of 20 additional pie charts. For each pie chart, participants were asked to estimate the percentage of the highlighted segment and enter their estimate in the provided text field.

Data Analysis

The data will be processed using the Python. The focus will be on data visualization, along with statistical comparisons to examine whether observed differences are statistically

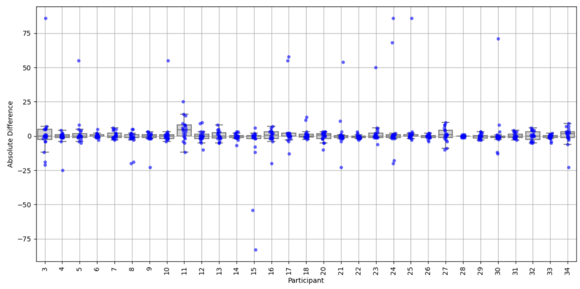

Figure 5. Errors with outliers

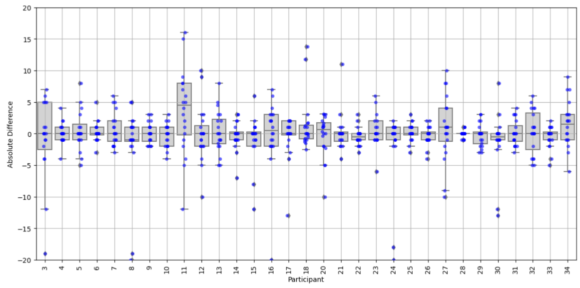

Figure 6. Errors without outliers.

significant. In particular, the following analyses will be used for each of the research questions.

The data will be processed using the `Python` programming language (Version `3.11`; (Python Software Foundation, 2023)). The analysis focuses on data visualization and statistical comparisons to evaluate whether observed differences are statistically significant. We rely on the `pandas` (McKinney, 2010), `NumPy` (Harris et al., 2020), `Matplotlib` (Hunter, 2007), `seaborn` (Waskom, 2021), and `SciPy` (Virtanen et al., 2020) libraries. Where appropriate, hypothesis tests (e.g., one-way ANOVA via `scipy.stats.f_oneway`) will be used to assess statistical significance. The anonymized data and analysis are available in the GitHub repository (De Preter, 2025).

Results

To ensure anonymity, all participants were assigned numerical IDs. One participant (ID 17) did not complete the test, and their responses were excluded from the analysis. After cleaning the dataset, 31 complete responses remained.

All calculations are based on the deviation from the correct percentage values. The analysis excluded the two example questions, resulting in 620 valid responses.

Figure 5 displays the raw results, which include several extreme outliers. These outliers are primarily caused by participants misinterpreting the unit of measurement—entering values in degrees instead of percentages. For instance, a participant might input “45” (degrees) when the correct answer was 25%.

To ensure a more accurate analysis, all responses with an absolute deviation greater than 20 percentage points were classified as outliers and excluded. This filtering removed 19 responses, leaving 601 for further analysis. The cleaned results are shown in Figure 6.

RQ1: Accuracy of Estimations

To evaluate how accurately participants estimated the pie chart segments, several statistical measures were calculated. On average, participants were off by 2.14 percentage points, as shown by the Mean Absolute Error (MAE). This means that most estimates were fairly close to the correct values.

The Standard Deviation (SD) and Root Mean Square Error (RMSE) were both 3.70, indicating that while many estimates were accurate, some participants made larger mistakes, which increased the overall spread of the results.

Finally, the Standard Error of the Mean (SEM) was 0.15, which shows that the average error is estimated with high precision across the 601 responses. This gives confidence in the reliability of the average error reported.

RQ2: Differences Between Participants

To determine the difference between participants, we examine whether there is a significant difference between the absolute errors of the participants.

A one-way ANOVA was conducted to compare the mean absolute errors (MAE) across 31 participants. The analysis yielded an F-statistic of 1.3868 and a p-value of 0.0847.

This p-value is slightly above the conventional significance threshold of 0.05, indicating that there is no statistically significant difference in the mean errors among the participants.

While the result is not statistically significant, the p-value is close to the threshold, suggesting that there may be some variation worth exploring further, especially with a larger sample size.

RQ3: Differences by Segment Size

A one-way ANOVA was conducted to compare the mean absolute errors between ’big’ and ’small’ graphs. The analysis yielded an F-statistic of 1.3312 and a p-value of 0.2492, indicating that the difference in estimation error (i.e., systematic over- vs. underestimation) between the two graph sizes is not statistically significant.

The mean error for big graphs was positive (0.3040), while for small graphs it was negative (-0.1119), suggesting a potential directional bias in estimation. However, this difference is not strong enough to be considered statistically meaningful. This result can be seen in Figure 7.

RQ4: Differences by Segment Orientation

A one-way ANOVA was conducted to compare the mean estimation errors between graphs with Bottom and Top orientations. The analysis yielded an F-statistic of 4.0771 and a p-value of 0.0446, which is statistically significant at the 0.05 level.

This suggests that graph orientation has a meaningful impact on participants’ estimation accuracy. Specifically, participants tended to underestimate values in Bottom-oriented graphs (mean error = -0.6592) and overestimate in Top-oriented graphs (mean error = 0.4399). This difference can be observed in Figure 8.

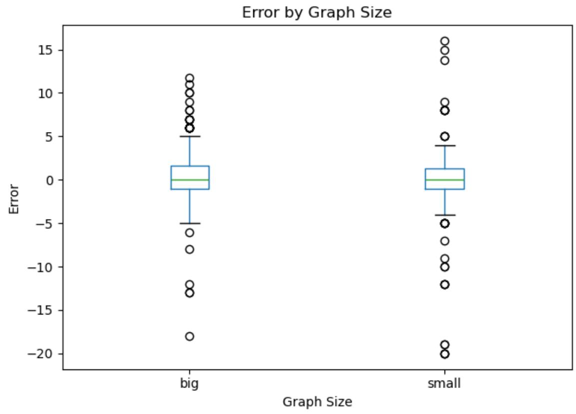

Figure 7. Comparison of errors between small and big segments.

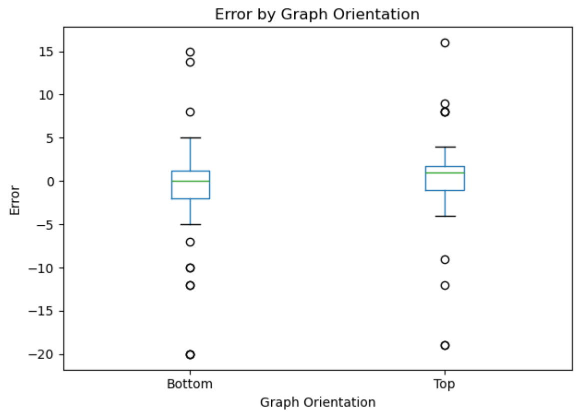

Figure 8. Comparison of errors between orientations.

Discussion

The present study examined the accuracy with which individuals estimate percentages in pie charts and explored whether estimation accuracy differs between small and large segments, as well as between different orientations. The results indicate that participants were generally able to estimate percentages with reasonable accuracy, as reflected by a mean absolute error (MAE) of 2.14 percentage points. This finding suggests that, contrary to some criticisms of pie charts (Siirtola, 2019), individuals can interpret them with a fair degree of precision under controlled conditions.

The analysis revealed no statistically significant differences in estimation accuracy between small and large segments, as indicated by the one-way ANOVA ($F = 1.3312$, $p = 0.2492$). It is important to note that all segments in this study were at least 5% of the chart. Therefore, no conclusions can be drawn regarding the accuracy of estimating segments smaller than 5%.

A significant effect of orientation was observed: participants tended to underestimate values in bottom-oriented graphs and overestimate values in top-oriented graphs ($F = 4.0771$, $p = 0.0446$). However, this finding should be interpreted with caution, as only a limited number of observations were available: out of 20 graphs, only 8 were evaluated for orientation, with just 4 graphs examined per category (top-oriented or bottom-oriented).

The absence of significant differences between participants ($p = 0.0847$) suggests that estimation ability is relatively consistent across individuals, at least within a population of data professionals without specialized visualization expertise. However, the near-threshold p-value indicates that a larger sample might reveal subtle individual differences, potentially linked to cognitive or perceptual factors.

Several limitations should be acknowledged. First, the study used a fixed set of pie charts with controlled characteristics, which may not fully represent the diversity of real-world visualizations. Second, the time constraint (10 minutes) may have influenced performance, as longer viewing times could potentially improve accuracy. Finally, the participant pool consisted of data professionals, which may limit generalizability to the broader population.

Future research could build on these findings by exploring scenarios that more closely resemble real-world use cases. For example, future studies could include pie charts with multiple highlighted segments rather than a single emphasized segment, as well as segments smaller than 5%, which were not represented in the current study. Such investigations would provide a more comprehensive understanding of how orientation, segment size, and visual complexity influence estimation accuracy in practical settings.

In conclusion, this study demonstrates that pie charts, when designed with high contrast and presented under controlled conditions, can be interpreted with reasonable accuracy. While orientation effects warrant further investigation, the findings challenge the notion that pie charts are inherently ineffective and suggest that their utility depends on thoughtful design and context of use.

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