Graphing and Summarizing Data for posters and manuscripts

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Overview of lecture

**Focus of lecture**: continuous outcomes

- Bar charts (85.6%*)
  - STD vs. SE
- Box and whiskers plots (5.3%*)
- Scatterplots (13.4%)
- Graphing paired data
- Graphs vs. tables
- Some guidelines

*Reported frequencies in one study of top physiology journals (Weissgerber et al. PLOS Biol. 13(4); e1002128)*
Tables and Figures

• Illustrate key findings in a clean and concise way

• Can be irrelevant or repetitive
**Example**

- Suppose we had a randomized study \( (n=30 \text{ per group}) \):
  - Control (no exercise intervention)
  - 6 months intense exercise

- Resting heart rate recorded
  - *continuous variable*
  - *our dependent variable*
## Overview of data

<table>
<thead>
<tr>
<th>group</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>SE</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>30</td>
<td>88.44</td>
<td>6.75</td>
<td>1.23</td>
<td>65.03</td>
<td>97.65</td>
</tr>
<tr>
<td>Exercise</td>
<td>30</td>
<td>77.39</td>
<td>8.33</td>
<td>1.52</td>
<td>60.18</td>
<td>99.50</td>
</tr>
</tbody>
</table>

Important and often overlooked – are these the correct summaries of your data?
General graphing

Outcome

Independent variable (what we control)
Bar Chart #1

Figure: Average heart rate (BPM) observed in controls (n=30) vs. exercise group (n=30)
## The Bar Chart

### What do bar charts tell you?

<table>
<thead>
<tr>
<th>group</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Error</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>30</td>
<td>88.44</td>
<td>6.75</td>
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<td>99.50</td>
</tr>
</tbody>
</table>
General rule: If only presenting specific summary statistics (ex: averages) for a few groups, put it in the text. If many group averages need to be presented, put them in a table so readers can see and compare the actual values.
Figure: Average heart rate (BPM) with error bars observed in controls vs. exercise group
Error Bars

• Many published figures say “with error bars” but then fail to clearly describe what exactly they mean by “error”

• Error bars can mean:
  • 95% Confidence intervals
  • +/- 1 SD
  • +/- 2 SD
  • +/- 1 SE
  • +/- 2 SE
Figure: Average heart rate (BPM) with error bars representing ± SD observed in controls (n=30) vs. exercise (n=30) group
Bar charts

• Compare bar chart # 2 with bar chart # 3

• What is each one telling you?

• Which should you present?
What is your goal for the figure?

1. To show group differences?

2. To show the scatter of the raw data?

First, a review of standard deviation (SD) and standard error of the mean (SEM)
Standard Deviation

• The average deviation from the mean in your observed data. It is an index of how individual data points are scattered.

• We compute SD so we can make inferences about the true population standard deviation. If it’s large, then we know values will vary a lot around the mean.

• Assuming normality, we expect 95% of heart rates in the control population to be within 75 and 102 BPM (± 2SD from the mean).
Standard error of the mean (SEM)

• The standard error (to be more precise, the standard error of the mean) is a property of our estimate of the mean. The SEM is equal to the SD divided by the square root of n.

• SD ≥ SE

• We expect 95% of all possible average values of HR from samples (of size n=30) repeatedly drawn from the control population to be within 86 and 91 BPM

• By plotting the means with ± 1 SEM, makes the data look as good as possible
Bar charts and Error Bars

• Regardless of what is used, it’s tempting (and common practice) to look at those error bars and make some conclusion about the statistical significance of the difference between groups

• Looking at bar chart # 2, you would perhaps say it is a statistically significant difference. Looking at bar chart #3, statistically insignificant
## Error bar overlap and its interpretation

<table>
<thead>
<tr>
<th>Type of Error Bar</th>
<th>Overlapping error bars</th>
<th>Non-overlapping error bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>No conclusion</td>
<td>No conclusion</td>
</tr>
<tr>
<td>SEM</td>
<td>Sample means not significantly different&lt;br&gt;&lt;i&gt;P-value &gt; 0.05&lt;/i&gt;</td>
<td>May still be statistically INSIGNIFICANT</td>
</tr>
<tr>
<td>95% CI</td>
<td>Can overlap by ~25% and still be significantly different</td>
<td>Sample means significantly different&lt;br&gt;&lt;i&gt;P-value &lt; 0.05&lt;/i&gt;</td>
</tr>
</tbody>
</table>
Bar charts

**General rule:** Bar charts are WAY over-used.

- Move away from bar charts!!! If you want to display the **variability of the raw data and allow readers to assess the validity of your analysis assumptions**, present RAW data if possible (and it IS possible with the sample sizes we generally see). There are much more informative figures to include (ex: box plots).

- If you want to follow your analysis and show how **precisely you have determined the group means** then present means with 95% CIs, along with summaries and p-values for group differences.

- If you want to **magnify small differences as well as hide unequal and/or small sample sizes and outliers**, present bar charts of the group means $\pm 1 \text{ SEM}$ and hope that readers think they are confidence intervals.
Bar charts

Some advantages of bar charts:

1. They are comfortable to most basic scientists
2. They anchor the data at zero*
3. They provide more area for displaying different colors

*Which is not useful if the differences between group means are small compared to the absolute magnitude of the responses or if data are not anchored at zero naturally (ex: log scale).
Figure: Box plot of heart rate (BPM) observed in controls (n=30) vs. exercise group (n=30). Diamonds represent the mean heart rate observed with the group, top/bottom of box represents the 75\textsuperscript{th} and 25\textsuperscript{th} percentiles respectively, whiskers represent minimum and maximum values.
Box and Whiskers plot with scatter

Figure: Box plot overlaying the scatter plot of heart rates (BPM) observed in controls (n=30) vs. exercise group (n=30). Diamonds represent the average group heart rate observed, upper/lower box represents the 75th/25th percentiles, whiskers represent min and max values. Individual data points are denoted by X.
Scatterplots

• Suppose you also collected participant age at baseline.

• You would like to examine the relationship between age and heart rate measured at baseline for all participants.
**Figure:** Scatter plot of heart rates (BPM) and age (years) observed in participants (n=60) at baseline screening visit showing a linear association (Pearson’s rho=0.52; p-value<0.001)
Paired Data

• Example: Suppose heart rates pre and post exercise observed from the same person (much more efficient design)

• Often, pre/post paired data are treated as two independent groups when presenting graphically
Figure: Average heart rate (BPM) $\pm$ 2 SD observed in controls (n=30) vs. exercise group (n=30)
Spaghetti plot

**Figure:** Spaghetti plot of heart rates (HR) pre and post exercise regimen in n=30 patients
Box and Whiskers Plot of HR Changes

**Figure:** Box plot overlaying the scatter plot of heart rates (BPM) changes observed in participants (n=30) post exercise program. Diamonds represent the mean heart rate observed with the group, upper/lower box represents the 75th/25th percentiles, whiskers represent min and max values.
Figures

• Graphs tend to make posters and papers prettier and can aid in interpretation if done correctly

• Even when a verbal description is possible, text may not convey very clearly the particular pattern of results, especially if you want to emphasize things like trends over time

• If you *must* make a graph, try to graph mostly raw data to avoid the issues we have discussed
Tables

• Useful when it is desirable to present exact values

• Used to complement the presentation in the text

• Allows the reader to find the numbers they are looking for

• Limit tables to those that provide essential information that could not be adequately presented in the text - a table with two or fewer columns and two or fewer rows is a good candidate for elimination
Table I: Average heart rate stratified by exercise group and age

<table>
<thead>
<tr>
<th>Exercise Group</th>
<th>N</th>
<th>Age</th>
<th>Average HR</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15</td>
<td>30-39</td>
<td>86.9(4.4)</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>40-49</td>
<td>88.3(4.3)</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>50-60</td>
<td>90.6(2.8)</td>
<td>reference</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>30-39</td>
<td>78.9(4.3)</td>
<td>0.44</td>
</tr>
<tr>
<td>Exercise</td>
<td>10</td>
<td>40-49</td>
<td>81.1(3.2)</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>50-60</td>
<td>80.8(4.6)</td>
<td>reference</td>
</tr>
</tbody>
</table>

HR=heart rate (BPM); N denotes group sample size; Within-group standard deviation is given in parentheses. *Corresponds to a two-sided t-test for differences in heart rates within each exercise group between each age group compared to the reference group (50-60 year olds).
Elements of an effective table

1. Reference all tables in the text

2. Make sure that all numbers agree with the text and that they all add up

3. Present mean (SD), not mean ± SD to avoid confusion with confidence intervals

4. Tables should be able to stand alone. Reader should not have to reference the text to understand your table. Explain all abbreviations.
5. Avoid sentences in the text that only direct you to the table:

– *Figure 1 shows the summary results for heart rates within each age group for both the exercise and control arms* vs.

– *There were no statistically significant differences in average heart rate between age groups in the control or exercise treatment arms (Figure 1)*
General Guidelines for both

1. Graphs or figures should not repeat data that has been included in the text, unless for emphasis

2. Graphs and tables should enhance knowledge, not confuse the reader

3. Clear and complete footnotes, legends, and axes titles are vital

4. Tables and figures should stand on their own