Table of Contents

Download Dataset

This data has been pre-processed from Steinmetz et al. (2019), and is hosted on Sciebo here: https://uni-bonn.sciebo.de/s/wjsBtZzUVjKaB3J. The code below downloads the data into a directory named **`data`**

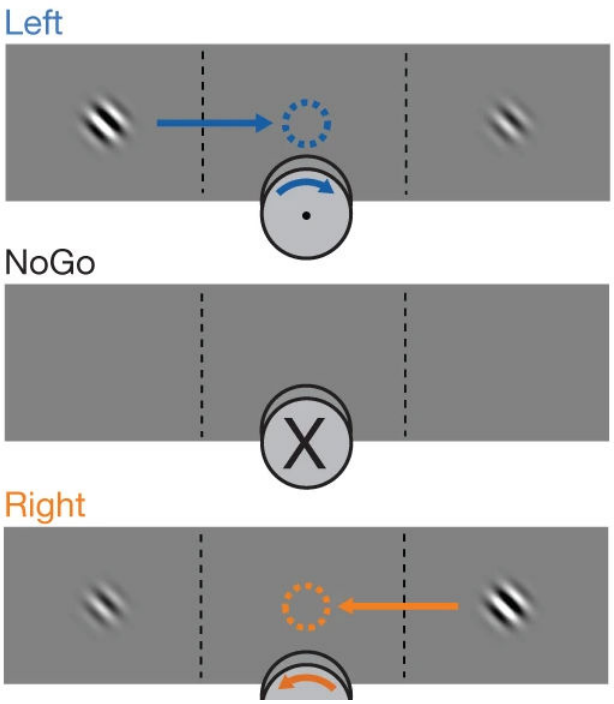
```
userpath(fullfile(fileparts(matlab.desktop.editor.getActiveFilename), "src"))
download_from_sciebo('https://uni-bonn.sciebo.de/s/wjsBtZzUVjKaB3J', 'data/steinmetz_all.csv')
```

```
Downloading file to data/steinmetz_all.csv
Done!
```

```
addpath(fullfile(fileparts(matlab.desktop.editor.getActiveFilename), "data"))
```

Analyzing Behavioral Task Performance: Psychometric Analysis on Ordered Categorical Data

In the experiment reported on by Steinmetz et al, 2019 in Nature, mice were tasked with turning a wheel to the left or right based on the relative contrast levels of two simultaneously-presented gradient stimuli:



When the left stimuli is brightest, in order to earn a reward, the mouse must turn the wheel to the right. Accordingly when the right stimili is brightest, the mouse must turn the wheel to the right. When both stimili have equal contrasts (including the case where no stimili are shown), the correct response is not to turn the wheel.

Analysis Goal: The `response_type` data encodes which way the mouse turned the wheel : -1 corresponds to a left turn, 1 to a right turn and 0 means that the wheel was not turned at all. In this notebook, we'll examine the `response_time` and `response_type` of each trial across all sessions, to determine whether the mice successfully performed the task, and whether the difference in contrast levels between the two stimuli affected their performance.

Calculating Group Statistics with `grpstats()`

How do the statistics on `response_time` and `response_type` change when the data is broken down into various groups? In this section, we'll practice using the `grpstats()` function to do this with tables.

`grpstats()` is a rich function that makes it possible to do a wide variety of analyses on a single line. It needs four pieces of information:

1. The **Table** it should do the calculation on.
2. The **Grouping Variable(s)** in the table that it should reference to know how break down the dataset.
3. The **Statistic(s)** that is should apply to each group.
4. The **Data Variables(s)** in the table that the statistics should be applied to.

Ways to use the `grpstats()` Function	**Description**
`grpstats(data, "group", "mean", "DataVars", "var")`	calculate the mean of `var` for each level of `group`
`grpstats(data, "group", ["mean", "median"], "DataVars", "var")`	calculate both the mean and median of `var` for each level of `group`
`grpstats(data, ["group1", "group2"], "mean", "DataVars", "var")`	calculate the mean of `var` for each level of both `group1` and `group2`
`grpstats(data, "group", "mean", "DataVars", ["var1", "var2"])`	calculate the mean of both `var1` and `var2` for each level of `group`

Exercises

We'll use the **`tableread`** function to load in data from a CSV file called `steinmetz_all.csv`.

Name the table **`data`**

```
data = readtable("data/steinmetz_all.csv")
```

`data` = 14420×16 table

...

	Var1	trial	active_trials	contrast_left	contrast_right
1	0	1	'True'	100	0
2	1	2	'True'	0	50
3	2	3	'True'	100	50
4	3	4	'True'	0	0
5	4	5	'True'	50	100
6	5	6	'True'	0	0
7	6	7	'True'	0	0
8	7	8	'True'	0	0
9	8	9	'True'	0	0
10	9	10	'True'	100	50
11	10	11	'True'	50	0
12	11	12	'True'	0	0
13	12	13	'True'	50	25
14	13	14	'True'	100	0

⋮

Example: Make a table showing the median response time for each `contrast_left` level.

```
grpstats(data, "contrast_left", "median", "DataVars", "response_time")
```

`ans` = 4×3 table

	contrast_left	GroupCount	median_response_time
1 0	0	7200	1.8906
2 25	25	1680	1.0516
3 50	50	1696	0.9825
4 100	100	3844	1.0205

Make a table showing the median response time for each `contrast_left` level.

```
grpstats(data, "contrast_right", "median", "DataVars", "response_time")
```

`ans` = 4×3 table

	contrast_right	GroupCount	median_response_time
1 0	0	5103	1.9046
2 25	25	2528	1.0682
3 50	50	2418	1.0152
4 100	100	4371	0.9802

Make a table showing the number of trials that each mouse performed.

```
grpstats(data, "mouse", "numel", "DataVars", "trial");  % shorter version:
groupsummary(data, "mouse")
```

Make a table showing the median `response_time` for each combination of `contrast_left` and `contrast_right` levels.

```
grpstats(data, ["contrast_left", "contrast_right"], "median",
"DataVars","response_time")
```

ans = 16×4 table

	contrast_left	contrast_right	GroupCount	median_response_time
1 0_0	0	0	2649	2.0940
2 0_25	0	25	738	1.0911
3 0_50	0	50	1078	1.0372
4 0_100	0	100	2735	1.0686
5 25_0	25	0	353	1.2178
6 25_25	25	25	255	1.2346
7 25_50	25	50	372	0.9908
8 25_100	25	100	700	0.9383
9 50_0	50	0	767	0.9989
10 50_25	50	25	348	0.9891
11 50_50	50	50	256	1.0538
12 50_100	50	100	325	0.9060
13 100_0	100	0	1334	1.0340
14 100_25	100	25	1187	1.0518

⋮

Make a table showing the number of trials that each mouse saw each combination of contrast_left and contrast_right levels

```
grpstats(data, ["mouse", "contrast_left", "contrast_right"], "numel",
"DataVars","trial")
```

ans = 158×5 table

	mouse	contrast_left	contrast_right	GroupCount	numel_trial
1 Cori_0_0	'Cori'	0	0	188	188
2 Cori_0_25	'Cori'	0	25	53	53
3 Cori_0_50	'Cori'	0	50	89	89
4 Cori_0_100	'Cori'	0	100	127	127
5 Cori_25_0	'Cori'	25	0	41	41
6 Cori_25_25	'Cori'	25	25	49	49
7 Cori_25_50	'Cori'	25	50	45	45
8 Cori_25_100	'Cori'	25	100	87	87
9 Cori_50_0	'Cori'	50	0	89	89
10 Cori_50_25	'Cori'	50	25	43	43
11 Cori_50_50	'Cori'	50	50	48	48
12 Cori_50_100	'Cori'	50	100	43	43
13 Cori_100_0	'Cori'	100	0	82	82
14 Cori_100_25	'Cori'	100	25	67	67

⋮

Let's make a mega statistics table. Calculate the median, mean, and std, and `meanci` (95% confidence intervals of the mean) for both the response time and response type, for every combination of `contrast_left` and `contrast_right` levels, for each `session_id`.

```
grpstats(data, ["session_id", "contrast_left", "contrast_right"], ["median",
"mean", "meanci"], "DataVars", ["response_type", "response_time"])
```

ans = 620×10 table

...

	session_id	contrast_left	contrast_right	GroupCount
1 5dd41e_0_0	'5dd41e'	0	0	46
2 5dd41e_0_25	'5dd41e'	0	25	17
3 5dd41e_0_50	'5dd41e'	0	50	33
4 5dd41e_0_100	'5dd41e'	0	100	31
5 5dd41e_25_0	'5dd41e'	25	0	14

	session_id	contrast_left	contrast_right	GroupCount
6 5dd41e_25_25	'5dd41e'	25	25	13
7 5dd41e_25_50	'5dd41e'	25	50	16
8 5dd41e_25_100	'5dd41e'	25	100	43
9 5dd41e_50_0	'5dd41e'	50	0	28
10 5dd41e_50_25	'5dd41e'	50	25	17
11 5dd41e_50_50	'5dd41e'	50	50	16
12 5dd41e_50_100	'5dd41e'	50	100	15
13 5dd41e_100_0	'5dd41e'	100	0	28
14 5dd41e_100_25	'5dd41e'	100	25	18

⋮

Plotting Group Statistics with `bar()` and `plot()`

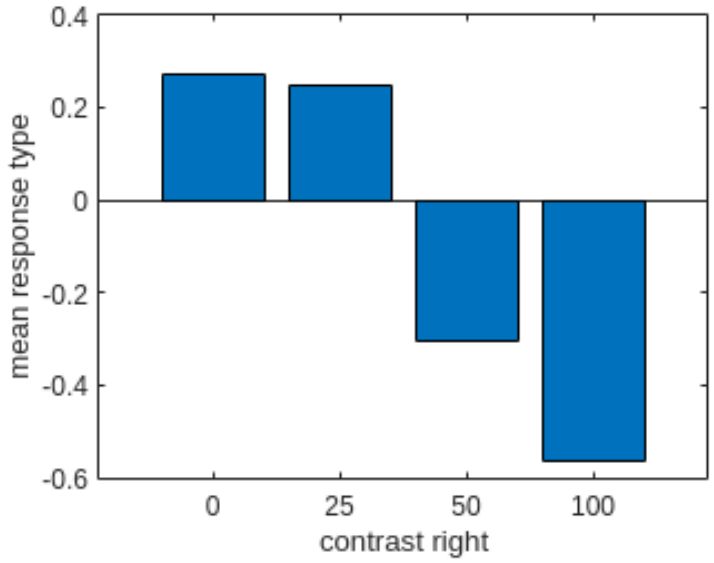
As the saying goes, "A picture is worth a thousand words." In this section, we'll combine the grouping statistics calculation to make a summary table, which is then passed into a plotting function.

Code	Description
`bar(x_data, y_data)`	make a bar plot
`bar(x_data, y_data, "red")`	make a bar plot with red bars
`barh(x_data, y_data)`	make a horizontal bar plot
`plot(x_data, y_data, 'o')`	make a point plot.
`xlabel("an x label")`	set the x label of a plot
`ylabel("a y label")`	set the y label of a plot

Exercises

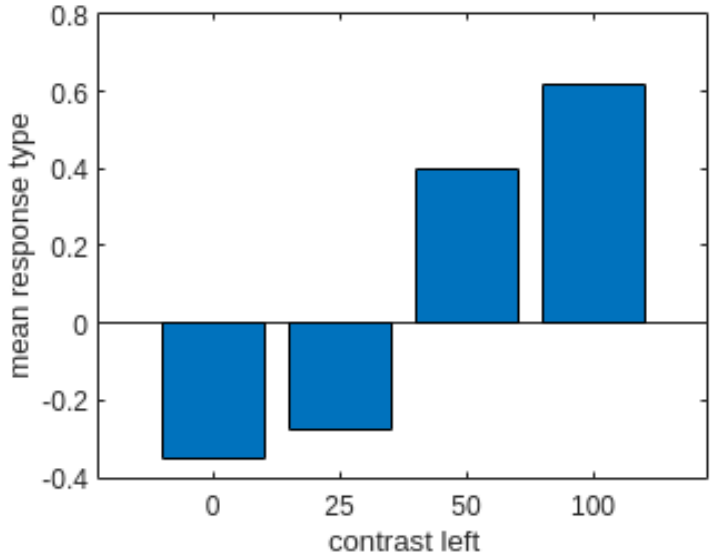
***Example*:** Make a bar plot showing the mean response type for each `contrast_right` level

```
summ = grpstats(data, "contrast_right", "mean", "DataVars", "response_type");
bar(categorical(summ.contrast_right), summ.mean_response_type)
xlabel("contrast right")
ylabel("mean response type")
```



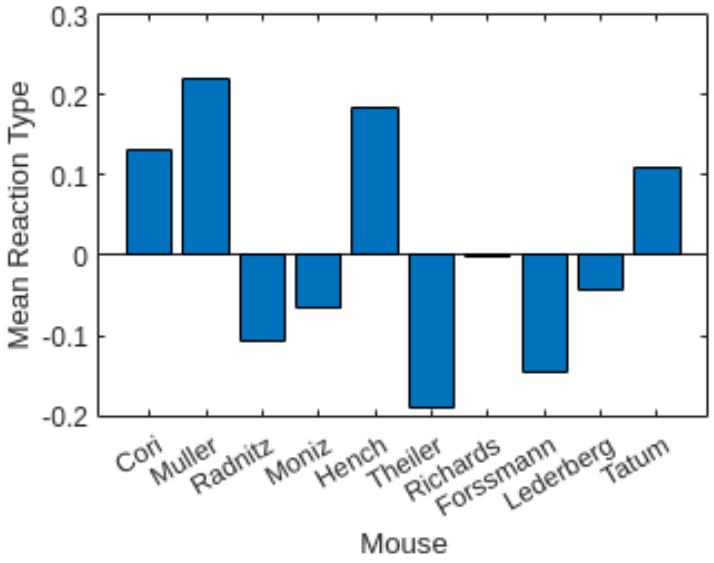
Make a bar plot showing the mean response type for each `contrast_left` level

```
summ = grpstats(data, "contrast_left", "mean", "DataVars", "response_type");
bar(categorical(summ.contrast_left), summ.mean_response_type)
xlabel("contrast left")
ylabel("mean response type")
```



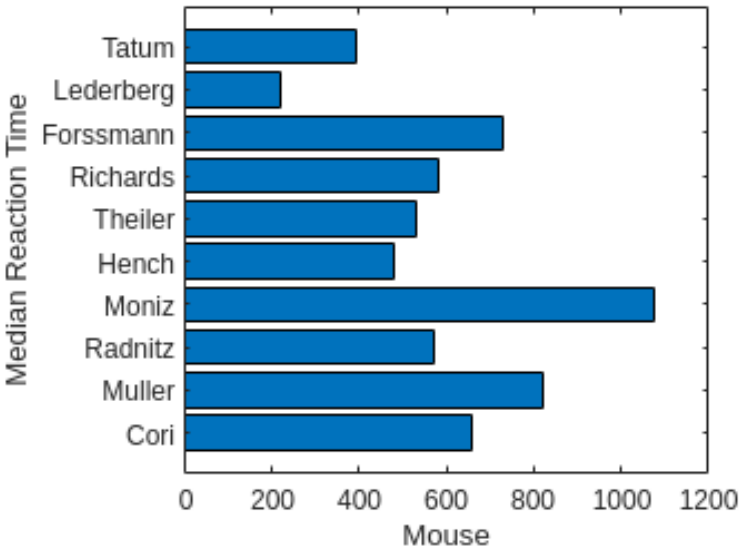
Make a bar plot showing the mean reaction type for each mouse.

```
summ = grpstats(data, "mouse", "mean", "DataVars", "reaction_type");
bar(summ.mouse, summ.mean_reaction_type)
xlabel("Mouse")
ylabel("Mean Reaction Type")
```



Make a bar plot showing the median reaction time for each mouse.

```
summ = grpstats(data, "mouse", "median", "DataVars", "reaction_time");
barh(summ.mouse, summ.median_reaction_time)
xlabel("Mouse")
ylabel("Median Reaction Time")
```



Calculating Group Statistics on Transformed Data

Making new columns in MATLAB tables

Code	Description
`data.column1`	access column 1 of table named data

`data.new_column = data.column2 - 4`	create a column called `new_column` where every row is column2 minus 4
`data.new_column = data.column1 + data.column2`	create a new column that is the row-wise sum of values in colum1 and column2
`data.new_column = data.column1 ~= 22`	create a new column called `new_column`, which is 1 where `column1` is not equal to 22
`data.new_column = abs(data.column2)`	make a new column that is the absolute value of values in column2

In the exercises below, let's practice making new columns in our table, and use them in new grouped statistics calculations.

Exercises

Example: Make a new column called `contrast_total` that is the sum of the two stimuli's contrast levels. Make a plot showing how median response time changes with `contrast_total`.

```
% Calculate New Value
data.contrast_total = data.contrast_left + data.contrast_right
```

`data` = 14420×17 table

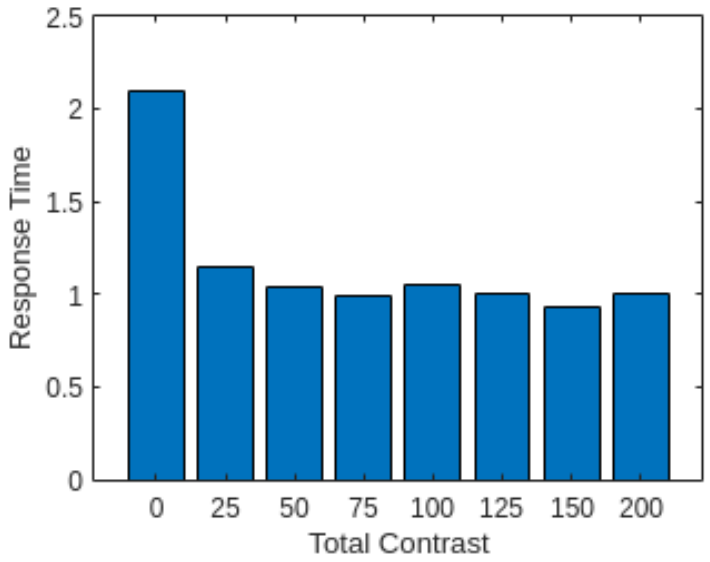
...

	Var1	trial	active_trials	contrast_left	contrast_right
1	0	1	'True'	100	0
2	1	2	'True'	0	50
3	2	3	'True'	100	50
4	3	4	'True'	0	0
5	4	5	'True'	50	100
6	5	6	'True'	0	0
7	6	7	'True'	0	0
8	7	8	'True'	0	0
9	8	9	'True'	0	0
10	9	10	'True'	100	50
11	10	11	'True'	50	0
12	11	12	'True'	0	0
13	12	13	'True'	50	25
14	13	14	'True'	100	0

⋮

```
% Calculate Group Statistics
summ = grpstats(data, "contrast_total", "median", "DataVars",
"response_time");

% Make Plot
bar(categorical(summ.contrast_total), summ.median_response_time)
xlabel('Total Contrast')
ylabel('Response Time')
```



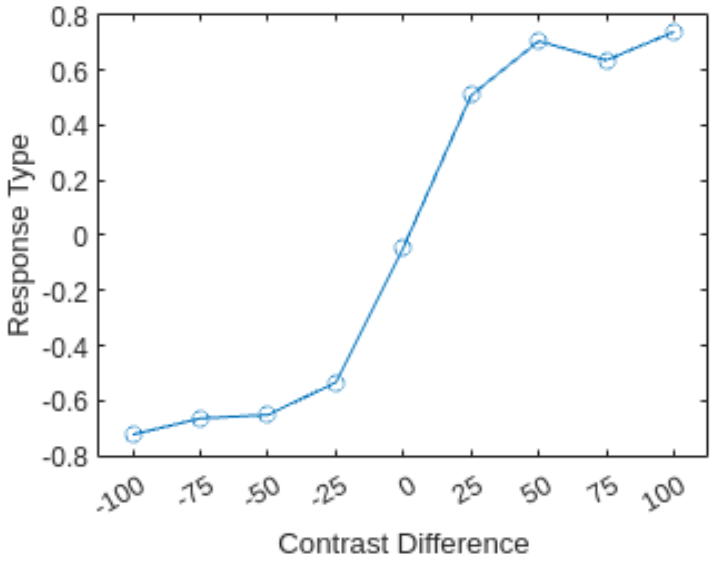
The mice had to make a decision of whether to move the wheel left or right based on the *difference* in contrast between the left and right stimulus, not on the actual levels of the data.

Make a new column called `contrast_diff` that contains the contrast difference between the left and right stimuli. Make a plot showing how mean `response_type` changes with `contrast_diff`.

```
% Calculate New Value
data.contrast_diff = data.contrast_left - data.contrast_right;

% Calculate Group Statistics
summ = grpstats(data, "contrast_diff", "mean", "DataVars", "response_type");

% Make Plot
plot(categorical(summ.contrast_diff), summ.mean_response_type, 'o-')
xlabel('Contrast Difference')
ylabel('Response Type')
```



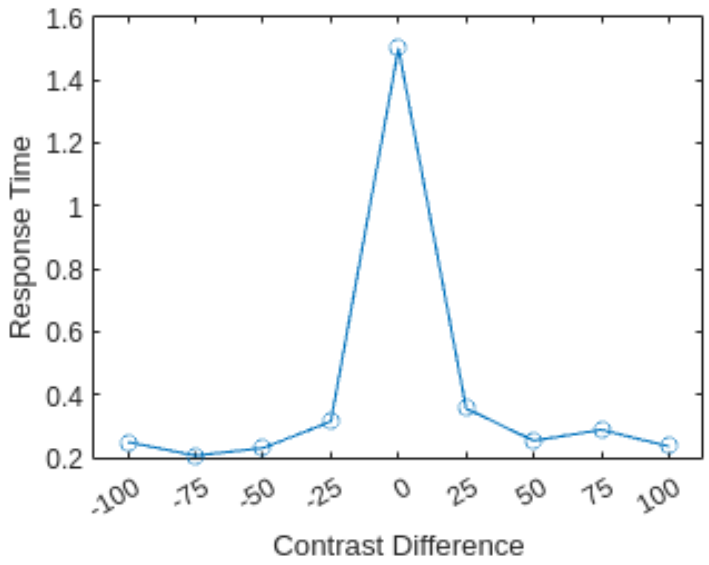
The mice were not allowed to respond immediately after the stimuli appeared; instead, they had to wait for the "go cue" to appear, which was at a randomized time point after the stimuli.

Let's calculate the a new `response_time_corrected` column, which subtracts the `gocue_time` from the `response_time`. Make a plot showing how median `response_time_corrected` changes with `contrast_diff`

```
% Calculate New Value
data.response_time_corrected = data.response_time - data.gocue_time;

% Calculate Group Statistics
summ = grpstats(data, "contrast_diff", "median", "DataVars",
"response_time_corrected");

% Make Plot
plot(categorical(summ.contrast_diff), summ.median_response_time_corrected,
'o-')
xlabel('Contrast Difference')
ylabel('Response Time')
```

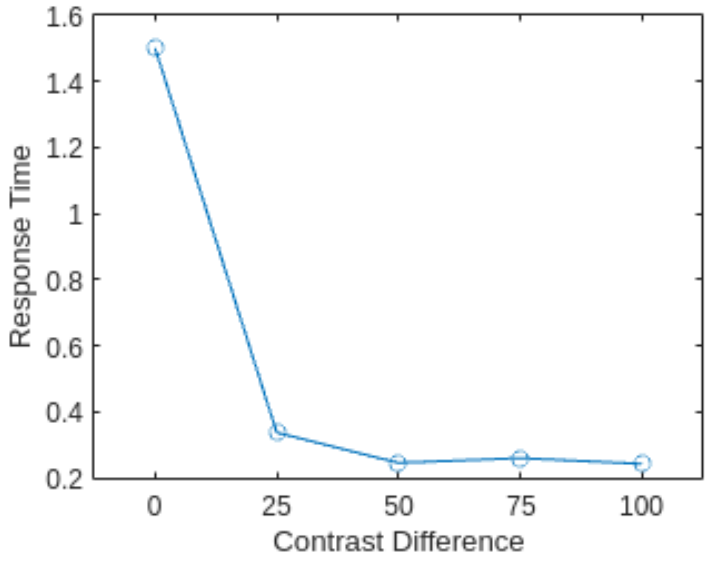


Instead of calculating the `contrast_diff`, let's calculate the `contrast_diff_absolute`, where the absolute value of the contrast difference is used, so it is always positive. This more-closely shows the decision that the mice had to make, and allows us to use twice as many values for each point estimation.

```
% Calculate New Value
data.contrast_diff_absolute = abs(data.contrast_diff);

% Calculate Group Statistics
summ = grpstats(data, "contrast_diff_absolute", "median", "DataVars",
"response_time_corrected");

% Make Plot
plot(categorical(summ.contrast_diff_absolute),
summ.median_response_time_corrected, 'o-')
xlabel('Contrast Difference')
ylabel('Response Time')
```



Putting Error Bars on Plots

When we calculate these group statistics in experimental science, it's good to represent them as *estimates* of a value you're trying to find. To do this, we need to calculate and plot errorbars on our plots.

Code	Description
`er = errorbar(x_data, y_data, errbar)`	make error bars that are symmetrical (good for `std` and `sem` errorbars)
`er = errorbar(x_data, y_data, errbar_neg, errbar_pos)`	make error bars that are asymmetrical (good for `meanci` errorbars)
`er.Color = [0 0 0]`	make the color of the errorbars black (RGB values)
`er.LineStyle = 'none'`	hide the connecting line that the `errorbar()` function generates
`hold on`	Make it so the next plot is drawn on top of the previous figure
`hold off`	Make it so the next plot is drawn on a new figure.
`categorical()`	Change numeric data into category data. Helps with controlling spacing in plots.

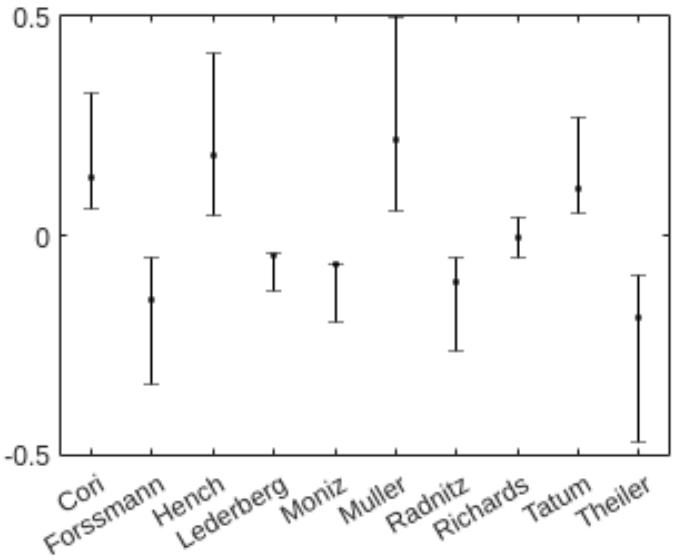
Example: Make a point plot showing the mean reaction_type for each mouse. Include 95% CI error bars.

```
summ = grpstats(data, "mouse", ["mean", "meanci"], "DataVars",
"reaction_type");

% Make an errobar plot with *just* the errorbars (no line connecting them)
er = errorbar(categorical(summ.mouse), summ.mean_reaction_type,
summ.meanci_reaction_type(:, 1), summ.meanci_reaction_type(:, 2));
er.Color = [0 0 0];
```

```
er.LineStyle = 'none';

% Add another plot to the same figure
hold on
plot(categorical(summ.mouse), summ.mean_reaction_type, '.k');
hold off
```

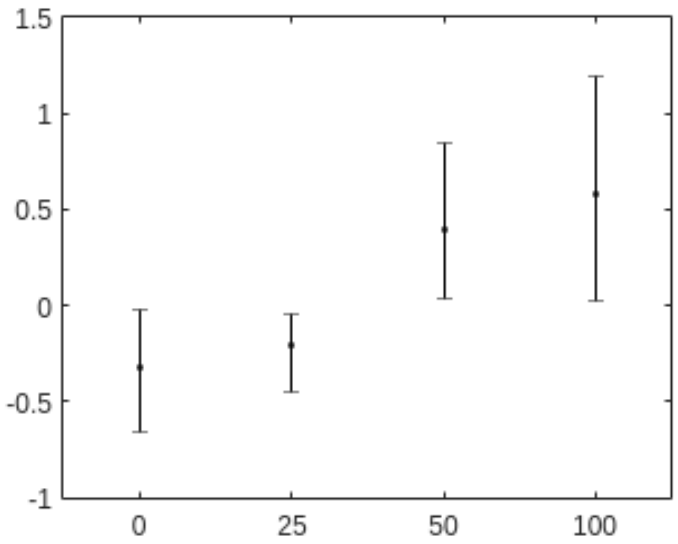


Make a point plot showing the mean reaction_type for each `contrast_left` level. Include 95% CI error bars.

```
summ = grpstats(data, "contrast_left", ["mean", "meanci"], "DataVars",
"reaction_type");

% Make an errobar plot with *just* the errorbars (no line connecting them)
er = errorbar(categorical(summ.contrast_left), summ.mean_reaction_type,
summ.meanci_reaction_type(:, 1), summ.meanci_reaction_type(:, 2));
er.Color = [0 0 0];
er.LineStyle = 'none';

% Add another plot to the same figure
hold on
plot(categorical(summ.contrast_left), summ.mean_reaction_type, '.k');
hold off
```

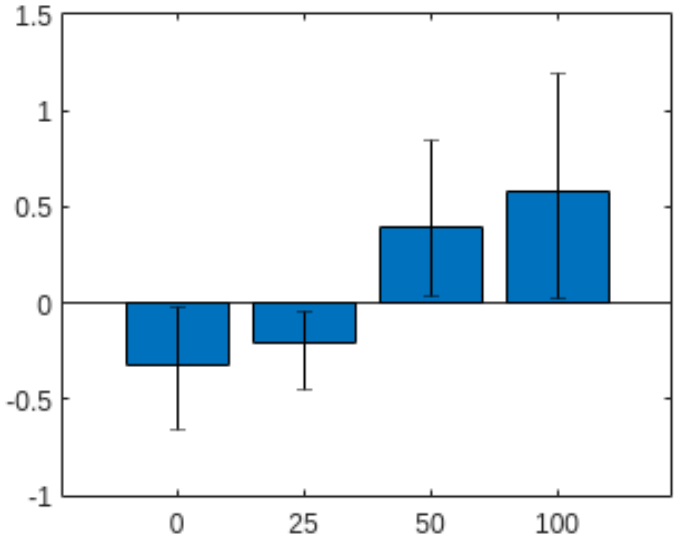


Make a bar plot showing the mean reaction_type for each `contrast_left` level. Include 95% CI error bars. (Note: make sure the bars don't hide the error bars.)

```
summ = grpstats(data, "contrast_left", ["mean", "meanci"], "DataVars",
"reaction_type");

bar(categorical(summ.contrast_left), summ.mean_reaction_type);

hold on
er = errorbar(categorical(summ.contrast_left), summ.mean_reaction_type,
summ.meanci_reaction_type(:, 1), summ.meanci_reaction_type(:, 2));
er.Color = [0 0 0];
er.LineStyle = 'none';
hold off
```

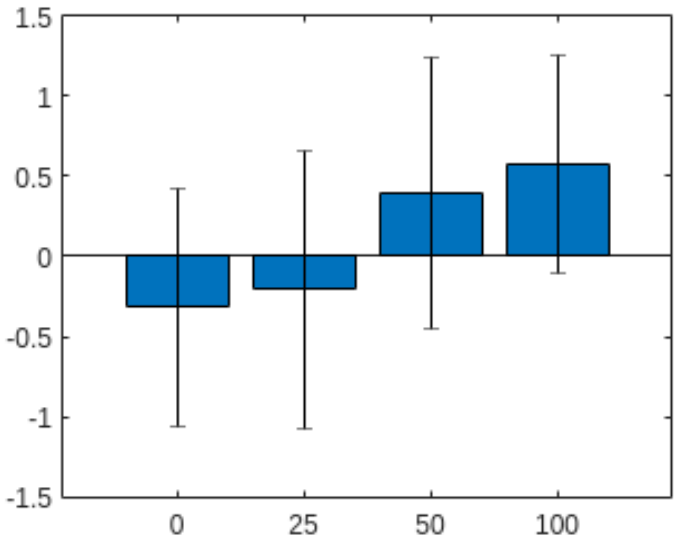


Make a bar plot showing the mean reaction_type for each contrast_right level. Use the standard deviation (`std`) to make the error bars.

```
summ = grpstats(data, "contrast_left", ["mean", "std"], "DataVars",
"reaction_type");

bar(categorical(summ.contrast_left), summ.mean_reaction_type);

hold on
er = errorbar(categorical(summ.contrast_left), summ.mean_reaction_type,
summ.std_reaction_type);
er.Color = [0 0 0];
er.LineStyle = 'none';
hold off
```

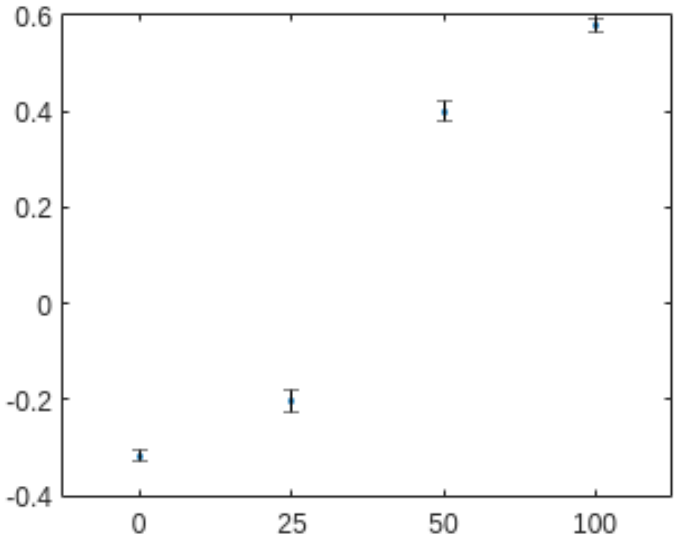


Make a point plot showing the mean reaction_type for each contrast_right level. Use the standard error of the mean (`sem`) to make the error bars.

```
summ = grpstats(data, "contrast_left", ["mean", "sem"], "DataVars",
"reaction_type");

plot(categorical(summ.contrast_left), summ.mean_reaction_type, '.');

hold on
er = errorbar(categorical(summ.contrast_left), summ.mean_reaction_type,
summ.sem_reaction_type);
er.Color = [0 0 0];
er.LineStyle = 'none';
hold off
```



Extra Demonstration: Exporting a Figure

Example: How multiple lines can be plotted on the same figure.

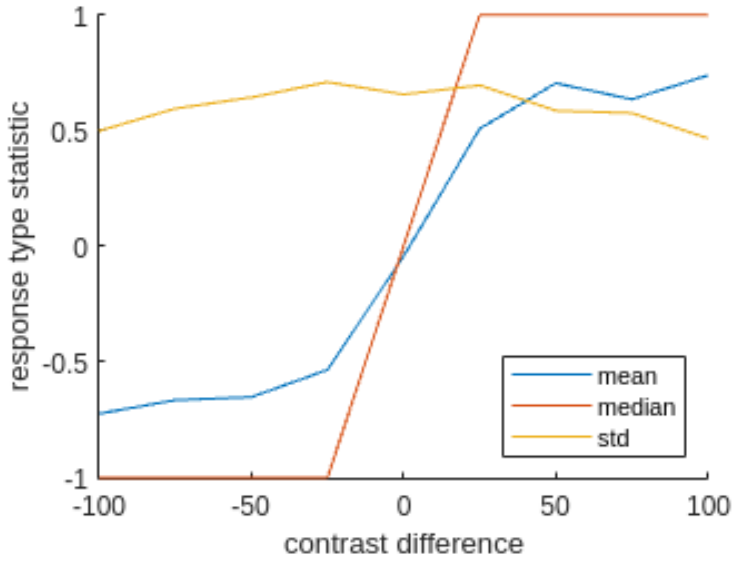
The code below makes a plot the mean, median and standard deviation of response type, grouped by contrast difference and save it to a .pdf file.

```
% generate statistics
summ = grpstats(data, "contrast_diff", ["mean","median","std"], "DataVars",
"response_type");

% Make the Plot
clf % clear the figure
hold on % freeze the figure for multiple lines
plot(summ.contrast_diff, summ.mean_response_type, "DisplayName","mean")
plot(summ.contrast_diff, summ.median_response_type, "DisplayName","median")
plot(summ.contrast_diff, summ.std_response_type, "DisplayName","std")
hold off % unfreeze

legend ("Location", "southeast") % show legend and set position
xlabel('contrast difference')
ylabel('response type statistic')

% Save the figure
fig_width = 12;
fig_height = 8;
set(gcf, 'PaperPosition', [0 0 fig_width fig_height]); %Position plot at
left hand corner with width 5 and height 5.
set(gcf, 'PaperSize', [fig_width fig_height]);
saveas(gcf, 'my_figure.pdf')
```


response type statistic
contrast difference
mean
median
std
1
0.5
0
-0.5
-1
-100
-50
0
50
100