



# Statistical Analysis

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Image: 'Hummingbird'  
[www.flickr.com/photos/27482923@N03/2760950147](http://www.flickr.com/photos/27482923@N03/2760950147)

Hummingbirds are nectarivores: herbivores which feed on the nectar in some species of flower.

In return for food, they pollinate the flower. This is an example of mutualism.

Hummingbird bills have evolved to suit their preferred source of food.



Researchers studying the evolution of hummingbirds take measurements of bill lengths and body sizes for comparative purposes.

The treatment of data collected in scientific investigations is known as **statistical analysis**.

Hummingbird with pollen

[http://www.thelensflare.com/gallery/p\\_hummingbirdpollenbeak\\_25599.php](http://www.thelensflare.com/gallery/p_hummingbirdpollenbeak_25599.php)

Let's compare two species of hummingbirds:



Ruby-throated hummingbird (*Archilochus colubris*)



Broadbilled hummingbird (*Cynanthus latirostris*)

*Is there a significant difference in bill-length and body mass between the ruby-throated and broadbilled hummingbirds?*

Important things to consider:

1. Sample size must be large enough to generate reliable data  
(and large enough to perform statistical tests)
2. Uncertainty and error of measurements.

# Measurements and Uncertainty

Uncertainty: the margin of error in a measurement.

e.g. this hummingbird weighs

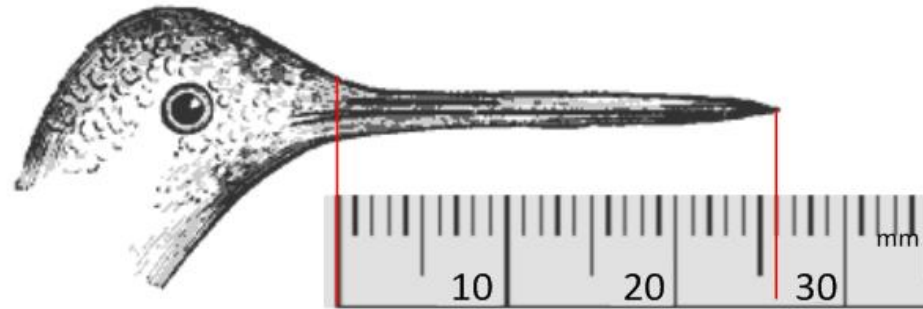
3.9g ( $\pm 0.1g$ ) for a digital measuring device

smallest division



Ruby-throat on a digital balance  
<http://www.bafrenz.com/birds/RTHuWeigh.htm>

Rulers have uncertainty at both ends:



[http://etc.usf.edu/clipart/7400/7401/hummer-beak\\_7401.htm](http://etc.usf.edu/clipart/7400/7401/hummer-beak_7401.htm)

26mm ( $\pm 1mm$ )  
( $\pm 0.5mm$  at both ends)

Analogue measurements are usually ( $\pm$  half the smallest measured division) The last decimal point is an estimate.

e.g.

this scale reads 3.9g

measured estimated

half so uncertainty is ( $\pm 0.5g$ )



# Now we can plug our raw data into Excel

Be neat from the start and save trouble later.

	A	B	C	D	E
1	<b>Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i></b>				
2		Bill length (mm) ( $\pm 0.1\text{mm}$ )			
3	n	<i>A. colubris</i>	<i>C. latirostris</i>		
4	1	13.0	17.0		
5	2	14.0	18.0		
6	3	15.0	18.0		
7	4	15.0	18.0		
8	5	15.0	19.0		
9	6	16.0	19.0		
10	7	16.0	19.0		
11	8	18.0	20.0		
12	9	18.0	20.0		
13	10	19.0	20.0		
14		<i>A. colubris</i>	<i>C. latirostris</i>		
15	<b>Mean</b>				
16	STDEV				
17					

Give the raw data table a title

Include uncertainty

Be consistent with the number of decimal places:  
don't use more than the limits of your equipment!  
(Format: number, and then adjust)

In this case,  $n=10$  for each species  
(total sample size is 20)

( $n$  doesn't have to be the same for both groups, though the closer the better.)

# Find the mean averages of each sample set

For data processing in Excel, it's easiest just go straight into the **Formulas** tab.

The screenshot shows the Microsoft Excel interface with the **Formulas** tab selected. The ribbon includes options like **More Functions**, **Statistical**, **Engineering**, **Cube**, and **Information**. The **Statistical** dropdown menu is open, showing the **AVERAGE** function selected. The spreadsheet below shows data for bill lengths of *A. colubris* and *C. latirostris*. A box is drawn around the cell for the mean of *A. colubris* in row 15, column B.

	A	B	C	D	E	F
1	<b>Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i></b>					
2		<b>Bill length (mm) (<math>\pm 0.1\text{mm}</math>)</b>				
3	n	<i>A. colubris</i>	<i>C. latirostris</i>			
4	1	13.0	17.0			
5	2	14.0	18.0			
6	3	15.0	18.0			
7	4	15.0	18.0			
8	5	15.0	19.0			
9	6	16.0	19.0			
10	7	16.0	19.0			
11	8	18.0	20.0			
12	9	18.0	20.0			
13	10	19.0	20.0			
14		<i>A. colubris</i>	<i>C. latirostris</i>			
15	<b>Mean</b>					
16	<b>STDEV</b>					

'More Functions'  
'Statistical'

To find the arithmetic mean, select **AVERAGE**.

Then highlight the data to be processed

Select this box

To calculate it yourself:

$$\text{mean } (\bar{x}) = \frac{\sum x}{n} \left( \frac{\text{sum of values}}{\text{sample size}} \right)$$

Hummingbirds.xlsx - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Add-Ins Nitro PDF

fx  $\Sigma$  Recently Used Financial Logical Text Date & Time Lookup & Reference Math More

Function Library

Name Manager Define Name Use in Formula Create from Selection Defined Names

Trace Precedents Trace Dependents Remove Arrows Show Error Evaluate Formula Audit

AVERAGE  $\times$   $\checkmark$   $fx$  =AVERAGE(B4:B13)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	<b>Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i></b>												
2		<b>Bill length (mm) (<math>\pm 0.1</math>mm)</b>											
3	n	<i>A. colubris</i>	<i>C. latirostris</i>										
4	1	15.0	18.0										
5	2	16.0	19.0										
6	3	13.0	20.0										
7	4	18.0	20.0										
8	5	19.0	20.0										
9	6	14.0	19.0										
10	7	16.0	18.0										
11	8	15.0	17.0										
12	9	15.0	18.0										
13	10	18.0	19.0										
14	<b>Mean</b>	=AVERAGE(B4:B13)											
15	STDEV												

**Function Arguments**

AVERAGE

Number1: [B4:B13] = {15;16;13;18;19;14;16;15;15;18}

Number2: [ ] = number

Select the data set for column 1 and hit OK.  
Do the same for column 2.

= 15.9

Returns the average (arithmetic mean) of its arguments, which can be numbers or names, arrays, or references that contain numbers.

**Number1:** number1,number2,... are 1 to 255 numeric arguments for which you want the average.

Formula result = 15.9

[Help on this function](#)

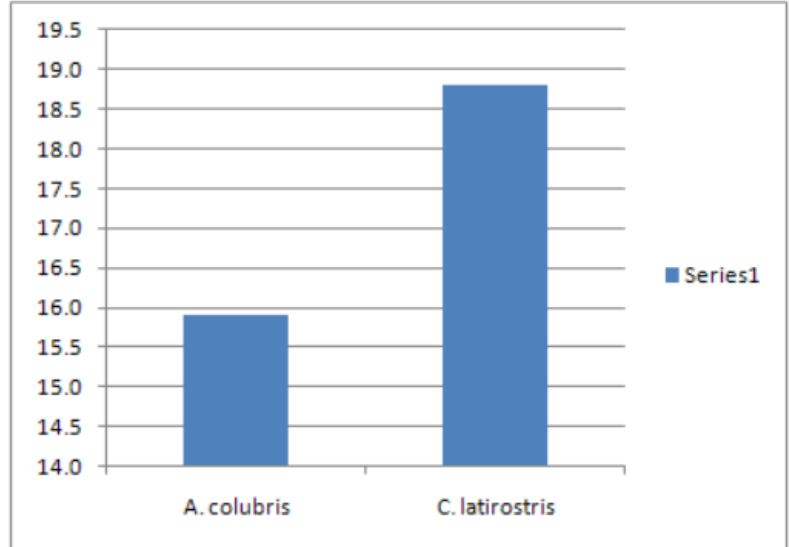
OK Cancel

# Plot your means on a graph:

The screenshot shows the Excel interface with the 'Insert' tab active. The 'Column' chart icon is circled in red. Below it, the '2-D Column' menu is open, showing various chart styles. The 'Clustering Column' option is selected, with a tooltip that reads: 'Compare values across categories by using vertical rectangles. Use it when the order of categories is not important or for displaying item counts such as a histogram.'

	A	B	C	D
1	<b>Comparing bill length in <i>A. colubris</i> and</b>			
2		<b>Bill length (mm) (<math>\pm 0.1\text{mm}</math>)</b>		
3	n	<i>A. colubris</i>	<i>C. latirostris</i>	
4	1	13.0	17.0	
5	2	14.0	18.0	
6	3	15.0	18.0	
7	4	15.0	18.0	
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10	7	16.0	19.0	
11	8	18.0	20.0	
12	9	18.0	20.0	
13	10	19.0	20.0	
14		<i>A. colubris</i>	<i>C. latirostris</i>	
15	<b>Mean</b>	15.9	18.8	
16	STDEV			
17				
18				

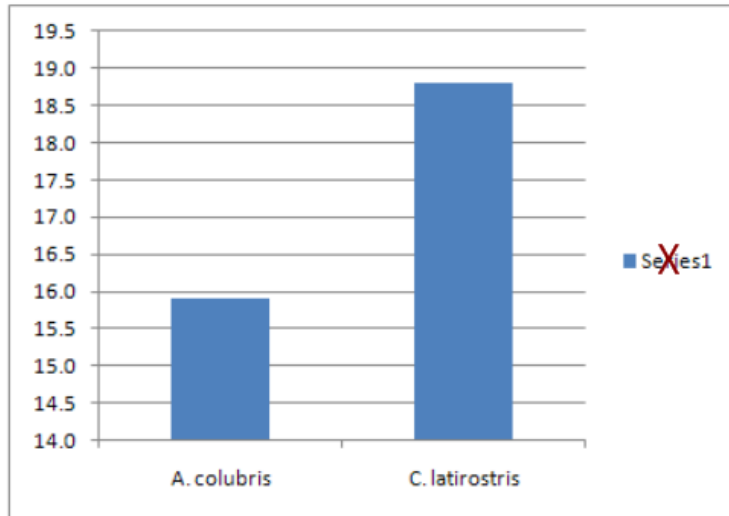
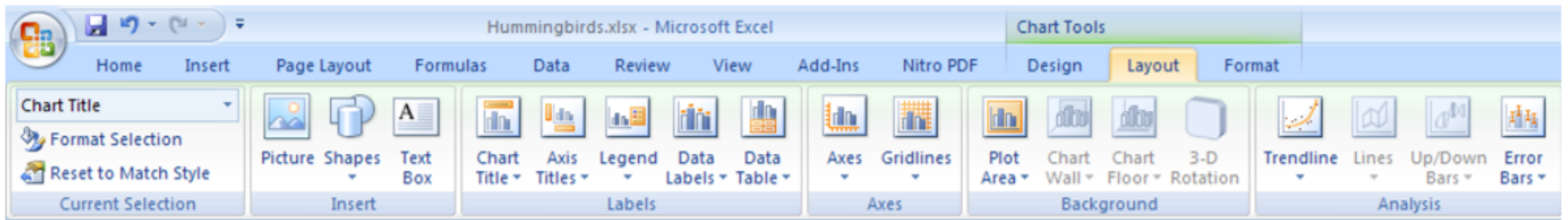
Go for the simplest style



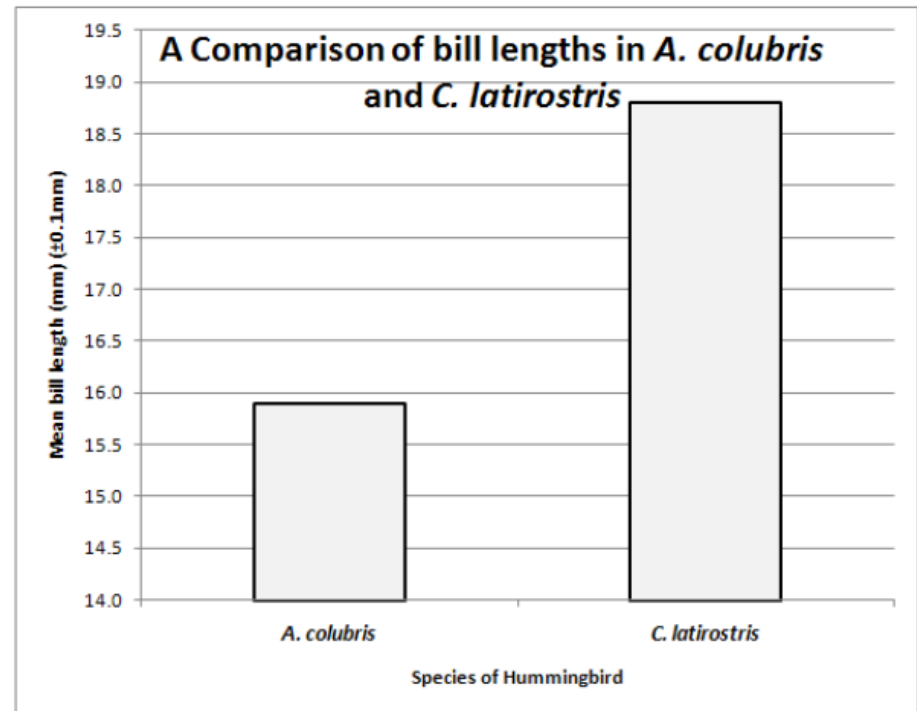
And then edit it.

Putting the headings and values together cuts down on messing around with Excel graphs





Edit using 'layout' options to meet acceptable standards.



Descriptive title

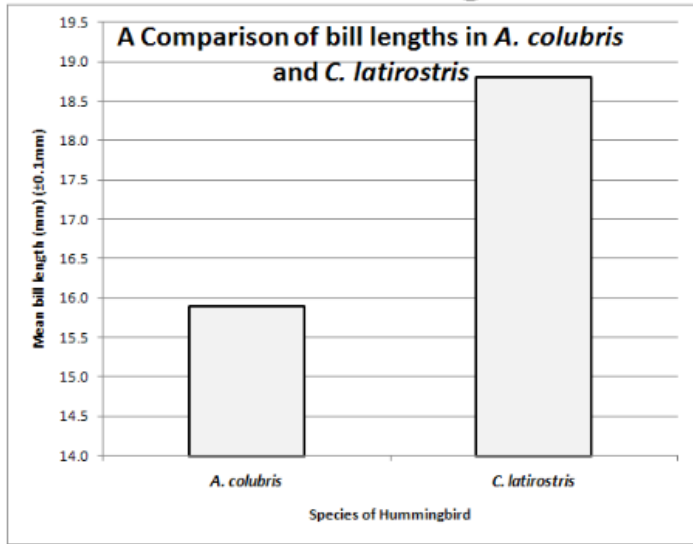
Axes labels

Get rid of 'series' box

Simple lines - no 3D or funny backgrounds

Colours are OK for slides, but not for printing - it can print messily.

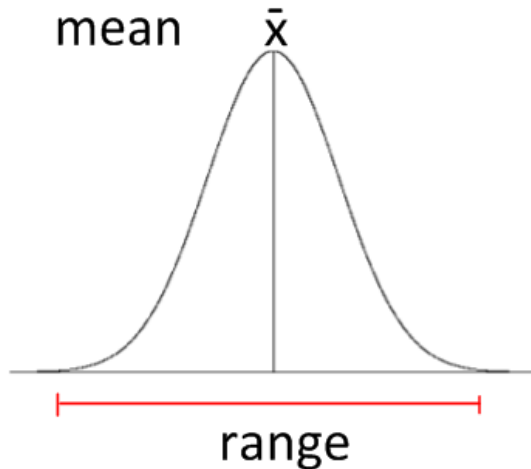
*C. latirostris* has a higher mean bill length than *A. colubris*...



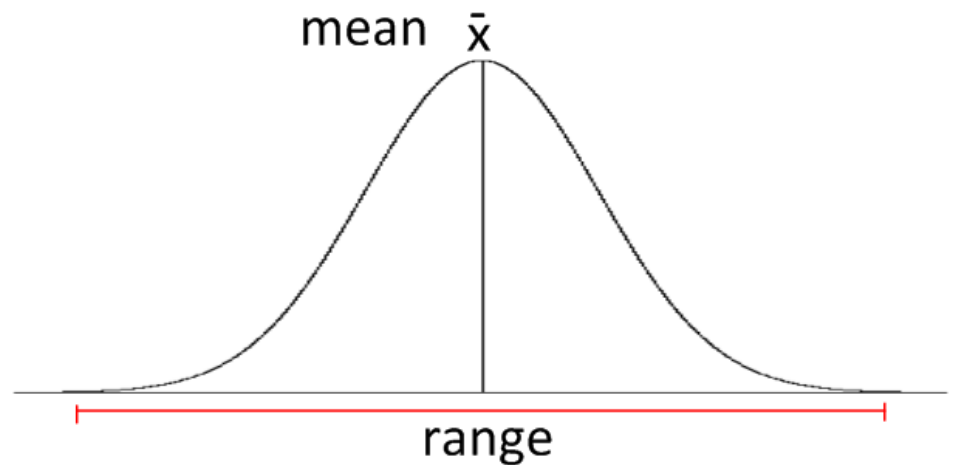
... but that is only part of the story.

The mean is a measure of the central tendency of the data, yet it tells us nothing of the spread of the data.

Our data could be clustered near the mean, or have high variability:



In this case, range (max - min values) is small - most of the recorded values are very **close to the mean**. This is known as a **NORMAL DISTRIBUTION**.



The mean here is the same, but there is a greater spread of data - there is **more variability**. This is also a **NORMAL DISTRIBUTION**.

What is the **range** of these data?

68, 56, 65, 75, 68, 74, 21, 67, 72, 69, 71, 67,

**max-min values** =      -      =

What is the **range** of these data?

68, 56, 65, 75, 68, 74, 21, 67, 72, 69, 71, 67,

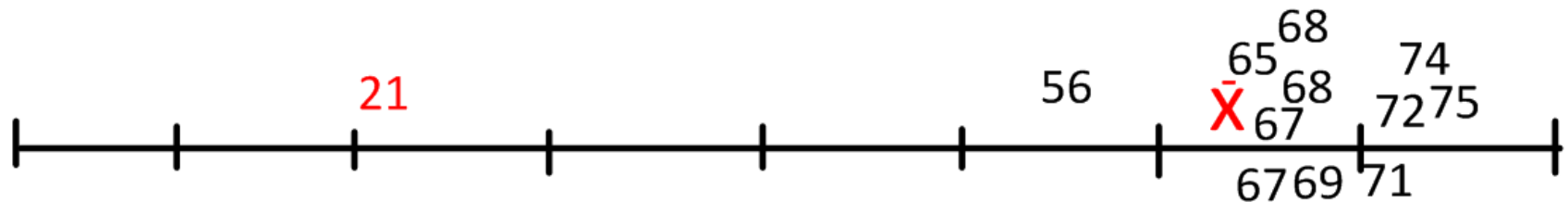
**max-min values = 75 - 21 = 54**

What is the **range** of these data?

68, 56, 65, 75, 68, 74, 21, 67, 72, 69, 71, 67,

**max-min values = 75 - 21 = 54**

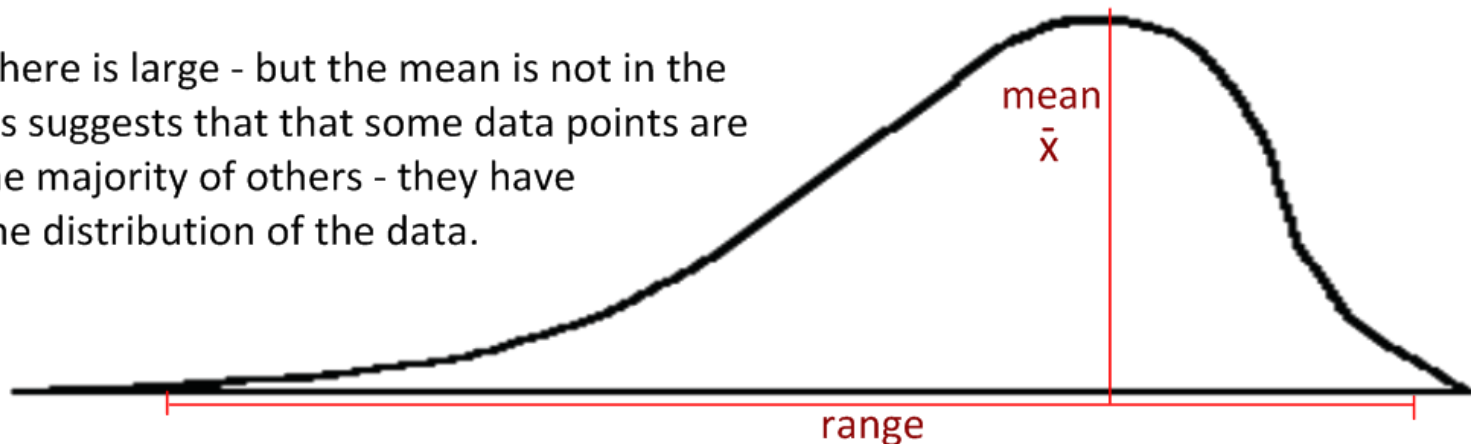
This suggests a large variability, but look more closely:



This value is far from the other data, causing the mean and range to be **skewed**.

The vast majority of values are clustered around this end of the distribution. The mean is not in the middle of this cluster, as it has been affected by the outlier, 21.

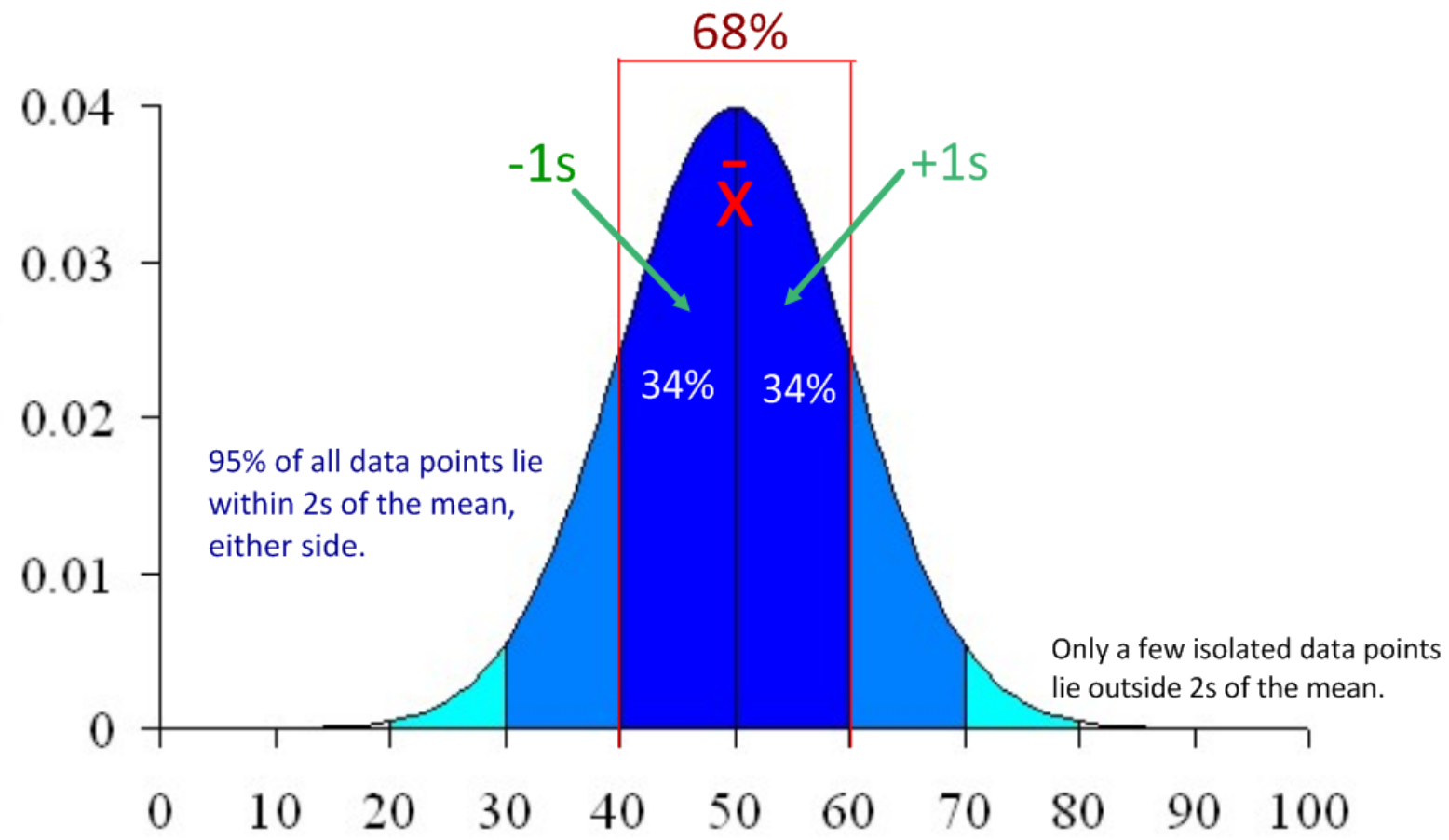
The range here is large - but the mean is not in the centre. This suggests that that some data points are far from the majority of others - they have **SKEWED** the distribution of the data.



**Standard deviation** is a measure of the **spread of most of the data.**

68% of all data fall within  $\pm 1$  standard deviation ( $s$ ) of the mean

This gives us a more reliable view of the 'true' spread of data - it is not affected by one or two anomalous results.



# Practice Question

A set of length measurements are taken with a mean of 2.5cm and a standard deviation of 0.5cm. Which of the following statements is true?

- A. 68% of all data lie between 2.5cm and 3.5cm
- B. 68% of all data lie between 1.5cm and 3.5cm
- C. 95% of all data lie between 1.5cm and 3.5cm
- D. 95% of all data lie between 2.0cm and 3.0cm

# Practice Question

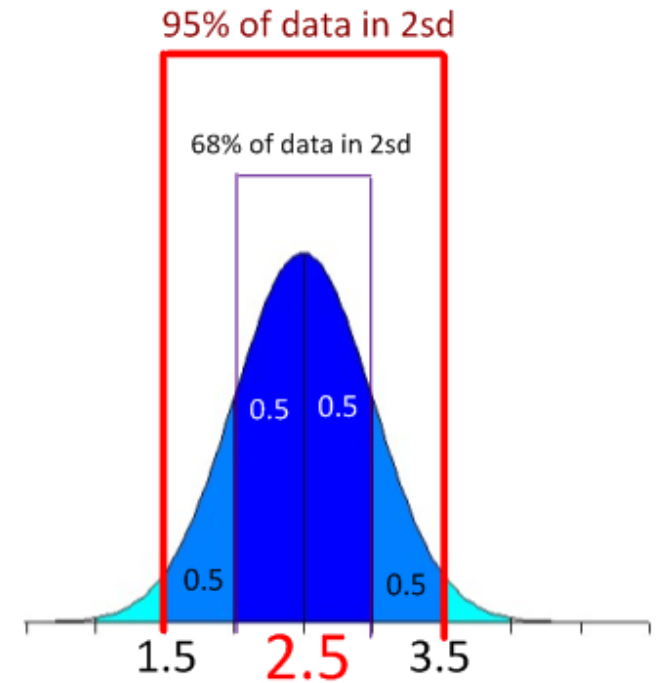
A set of length measurements are taken with a **mean of 2.5cm** and a **standard deviation of 0.5cm**. Which of the following statements is true?

- A. 68% of all data lie between 2.5cm and 3.5cm
- B. 68% of all data lie between 1.5cm and 3.5cm
- C. 95% of all data lie between 1.5cm and 3.5cm**
- D. 95% of all data lie between 2.0cm and 3.0cm

One sd = 0.5cm

68% of a data are within  $\pm 1sd$   
So 68% are between 2.0cm and 3.0cm

95% of a data are within  $\pm 2sd$   
So 95% are between 1.5cm and 3.5cm





# Practice Question

A set of data looks like this: 4, 5, 5, 5, 6, 6, 6, 7, 7, 9 with a mean of 6.

Which of the following is the best estimate of standard deviation?

A. 0

B. 1

C. 6

D. 5

# Practice Question

A set of data looks like this: 4, 5, 5, 5, 6, 6, 6, 7, 7, 9 with a mean of 6.

  
most data are the mean  $\pm 1$

*Standard deviation* is a measure of  
where most of data (68%  $\pm 1$ sd) lie

Which of the following is the best estimate of standard deviation?

A. 0

B. 1

C. 6

D. 5

# How can I find the mean and standard deviation on my calculator?

It's always a good idea to read the instructions...



- 1. Start up the calculator and select 'STAT' from the Main Menu.
- 2. If there is already data in there, hit this button:

	List 1	List 2	List 3	List 4
1				
2				
3				
4				
5				

SRTA SRTD DEL DELA INS

	List 1	List 2	List 3	List 4
1				
2				
3				
4				
5				

SRTA SRTD DEL DELA INS

- 3. And then hit DEL-A to clear it.
- 4. Now you can add your new data into the first column.  
(Do one set at a time)

- 5. To find the statistical data:

	List 1	List 2	List 3	List 4
1	400			
2	455			
3	390			
4	450			
5	360			

400.  
GRPH CALC TEST INTR DIST

	List 1	List 2	List 3	List 4
1	400			
2	455			
3	390			
4	450			
5	360			

400.  
1VAR 2VAR REG SET

And then...

So what does it mean?

mean

sum of all values

standard deviation (check it on Excel)

Hit the EXIT button to go back to your list.

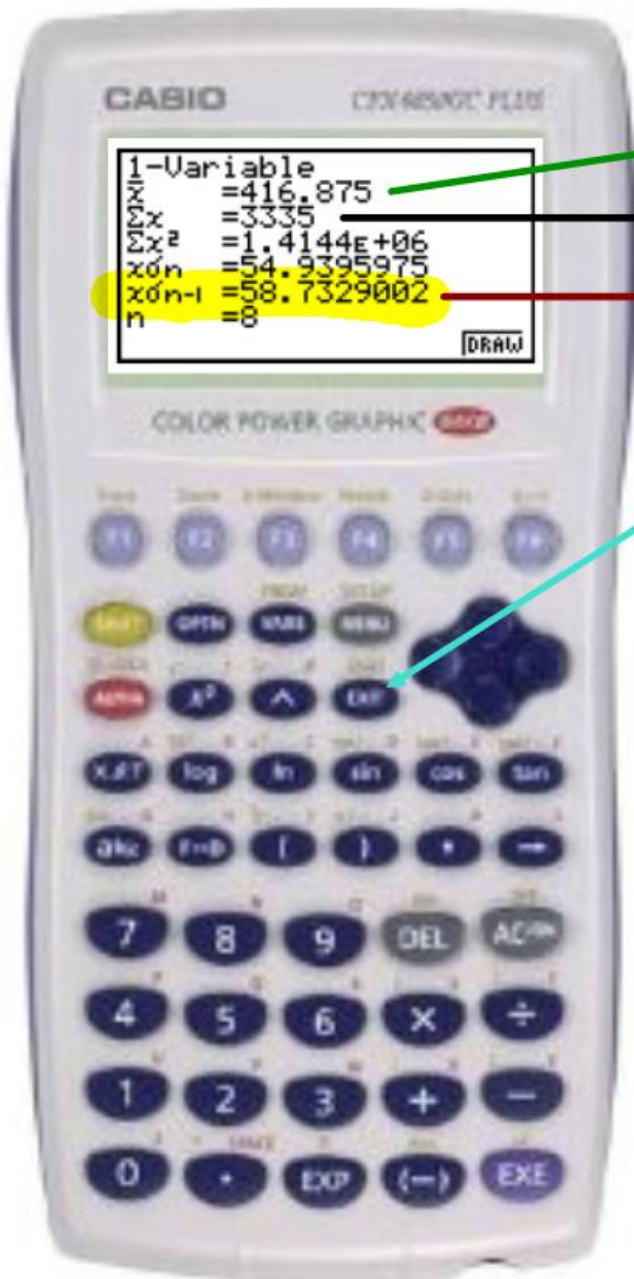
You can use your GDC for all kinds of statistical tricks, so spend some time learning how to make it work.

Casio screenshots taken from

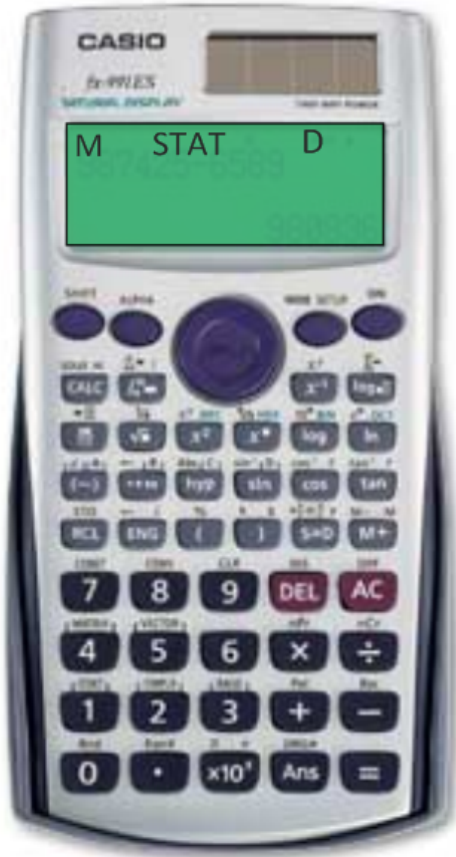
[http://www.keymath.com/documents/da2/CalculatorNotes/CFX9850/DA\\_CFX-9850\\_01.pdf](http://www.keymath.com/documents/da2/CalculatorNotes/CFX9850/DA_CFX-9850_01.pdf)

For Texas Instruments help, visit:

<http://click4biology.info/c4b/1/gcStat.htm>



# Using a Scientific Calculator to find Standard Deviation

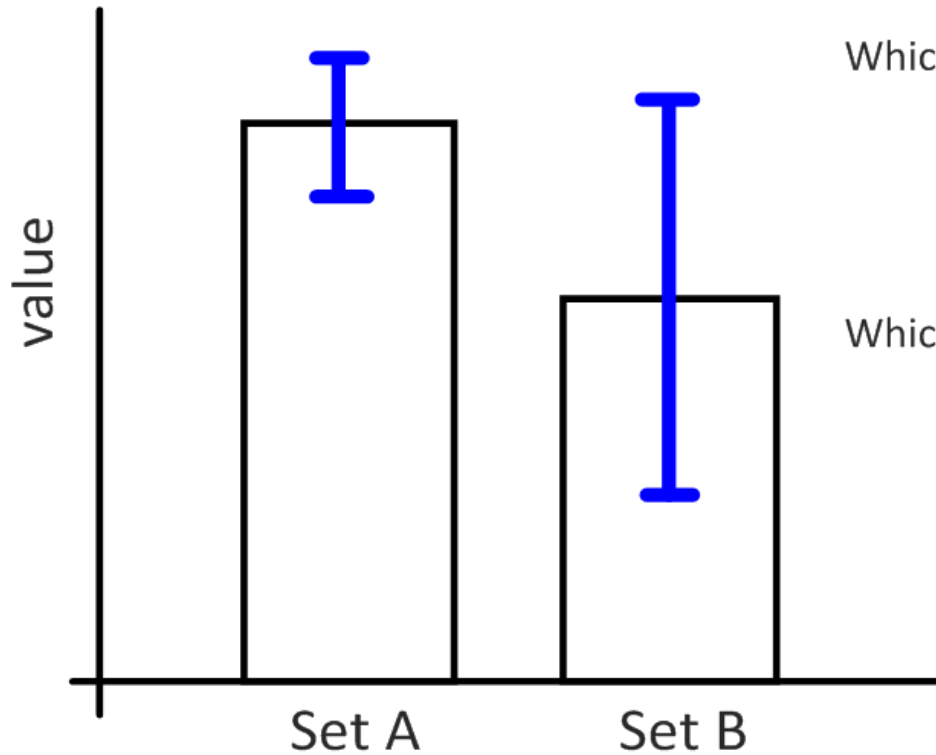


1. ON - MODE  (STAT - statistics)
2. SHIFT   
then choose 2:Data
3. Delete old data and enter new data  
(enter number, then )
4. At the bottom of the data:  
SHIFT  (Stat)  
and then hit 5:Var
5. Select 4:  $x\delta n-1$  ← Standard Deviation
6. And then hit  when the table comes up.

The **standard deviation** will appear at the bottom of the column.

# Error bars are a graphical representation of the variability of data

We can plot error bars to represent range, standard deviation, standard deviation or other estimates of variability. For us, standard deviation is usually the most useful.

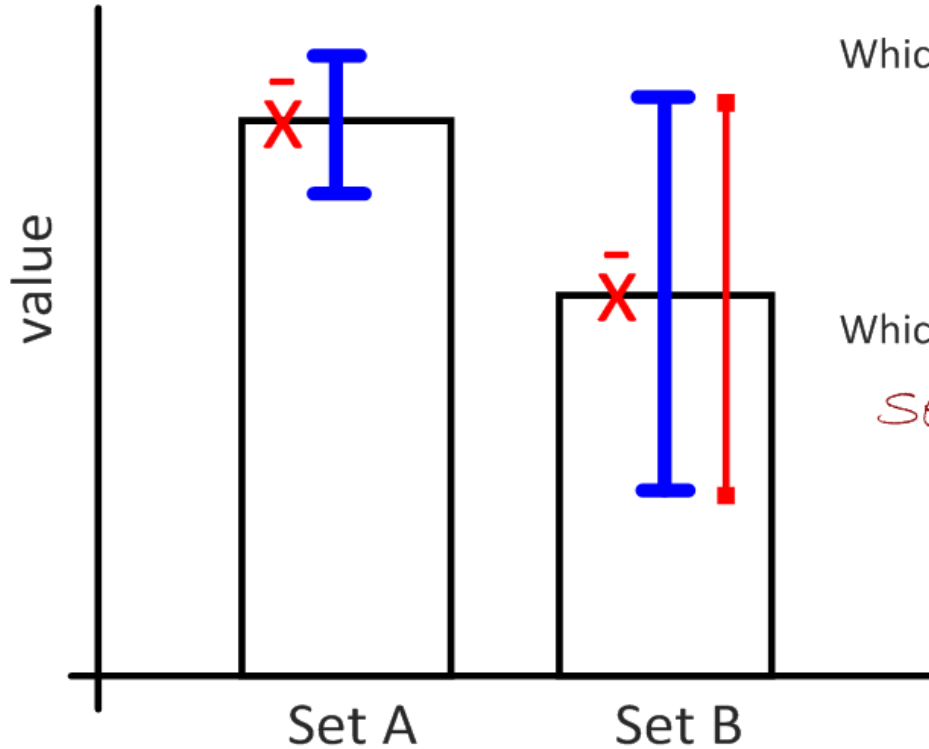


Which of these sets of data has the largest mean?

Which set has the greatest variability in the data?

# Error bars are a graphical representation of the variability of data

We can plot error bars to represent range, standard deviation, standard deviation or other estimates of variability. For us, standard deviation is usually the most useful.



Which of these sets of data has the largest mean?

*Set A*

Which set has the greatest variability in the data?

*Set B: large standard deviation  
= high variability*

# Using Excel to calculate Standard Deviation:

The screenshot shows the Microsoft Excel interface with the 'Formulas' tab selected. The 'More Functions' button is circled in red, and its dropdown menu is open, showing various function categories. The 'STDEV' function is highlighted in yellow. The background spreadsheet shows data for comparing bill lengths in *A. colubris* and *C. latirostris*.

Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i>		
Bill length (mm) ( $\pm 0.1$ mm)		
n	<i>A. colubris</i>	<i>C. latirostris</i>
1	13.0	17.0
2	14.0	18.0
3	15.0	18.0
4	15.0	18.0
5	15.0	19.0
6	16.0	19.0
7	16.0	19.0
8	18.0	20.0
9	18.0	20.0
10	19.0	20.0

**STDEV** (not STDEVA)

Highlight raw data only

The screenshot shows the 'Function Arguments' dialog box for the STDEV function. The 'Number1' field is set to 'B4:B13', which corresponds to the raw data for *A. colubris* in the spreadsheet. The 'Number2' field is empty. The dialog box displays the formula result as 1.91195072.

Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i>		
Bill length (mm) ( $\pm 0.1$ mm)		
n	<i>A. colubris</i>	<i>C. latirostris</i>
1	13.0	17.0
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6	16.0	19.0
7	16.0	19.0
8	18.0	20.0
9	18.0	20.0
10	19.0	20.0

Function Arguments

STDEV

Number1: B4:B13 = {13;14;15;15;16;16;18;18;19}

Number2: = number

= 1.91195072

Estimates standard deviation based on a sample (ignores logical values and text in the sample).

Number1: number1,number2,... are 1 to 255 numbers corresponding to a sample of a population and can be numbers or references that contain numbers.

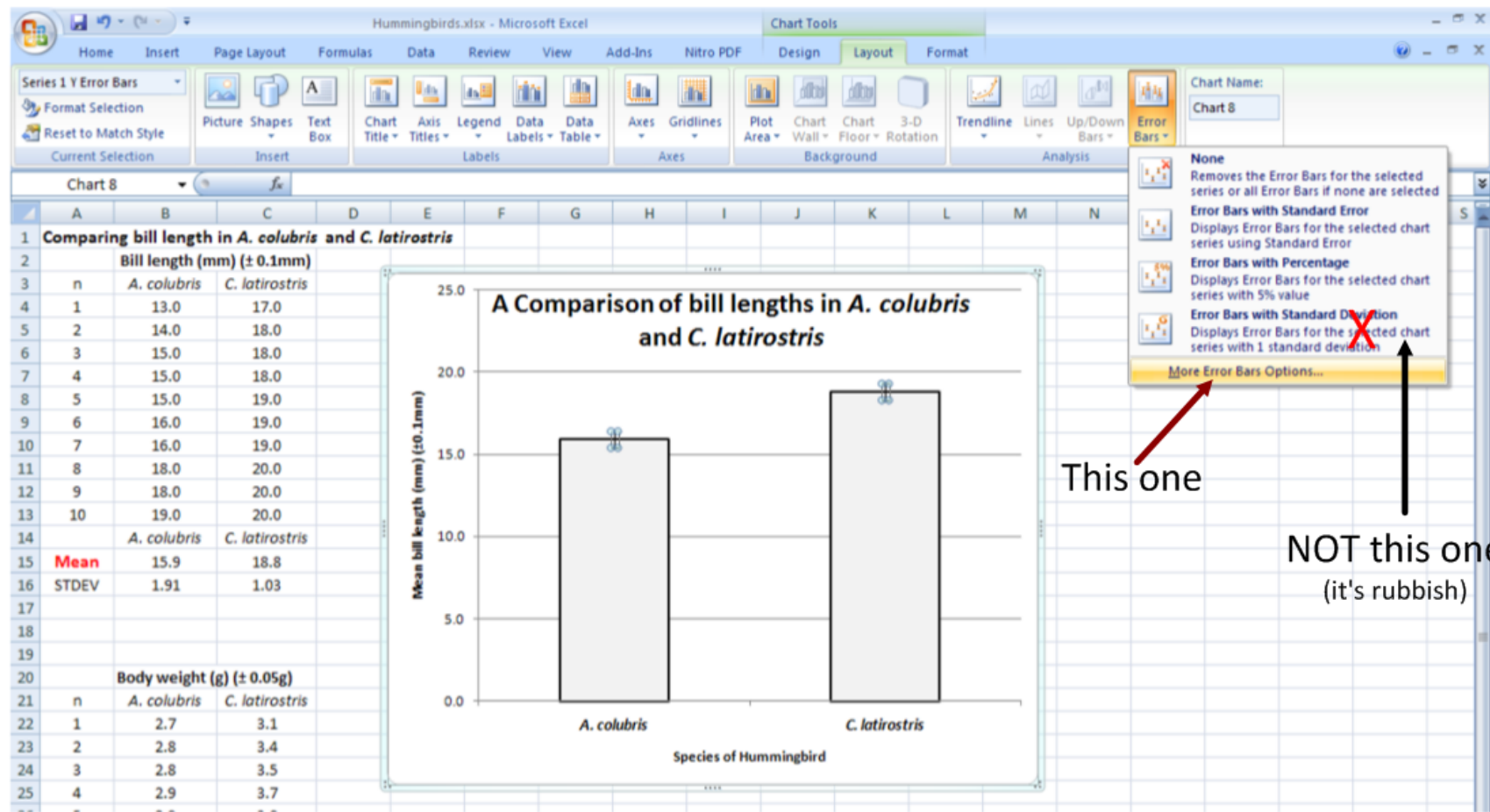
Formula result = 1.91195072

[Help on this function](#)

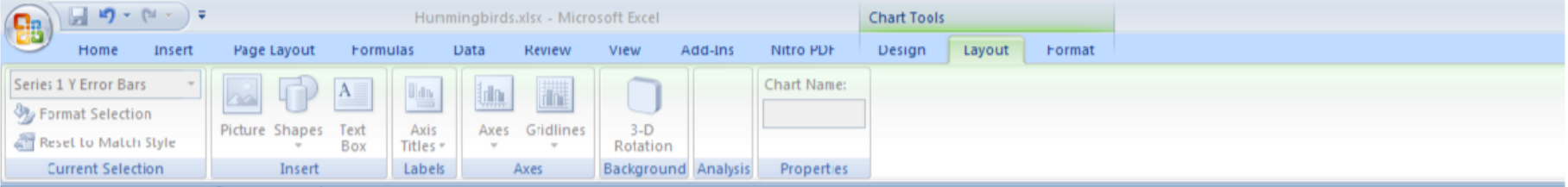
OK Cancel



# Plot standard deviation as error bars on the graph:



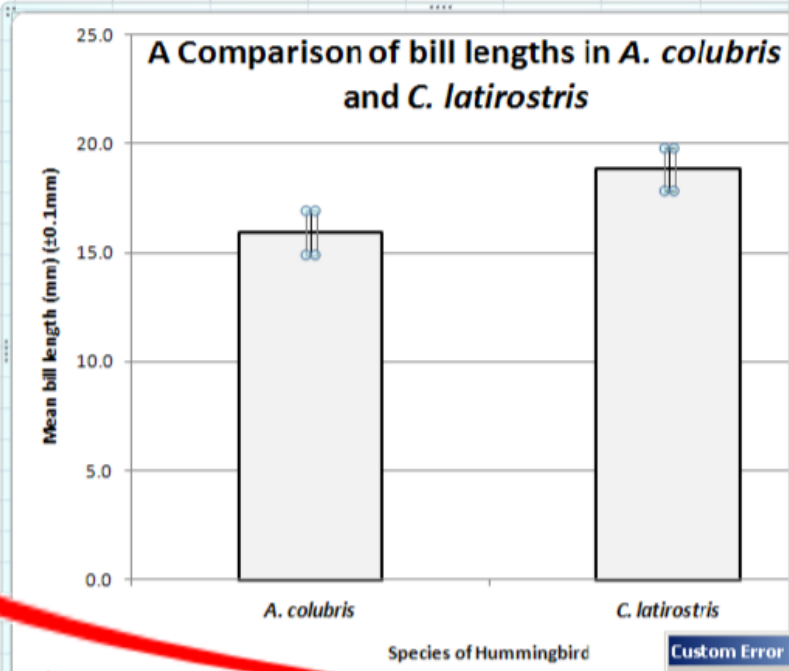
# Plot standard deviation as error bars on the graph:



Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i>			
	Bill length (mm) ( $\pm 0.1\text{mm}$ )		
n	<i>A. colubris</i>	<i>C. latirostris</i>	
1	13.0	17.0	
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5	15.0	19.0	
6	16.0	19.0	
7	16.0	19.0	
8	18.0	20.0	
9	18.0	20.0	
10	19.0	20.0	
	<i>A. colubris</i>	<i>C. latirostris</i>	
<b>Mean</b>	15.9	18.8	
<b>STDEV</b>	1.91	1.03	

Body weight (g) ( $\pm 0.1\text{g}$ )			
n	<i>A. colubris</i>	<i>C. latirostris</i>	
1	2.7	3.1	
2	2.8	3.4	
3	2.8	3.5	
4	2.9	3.7	
5	2.9	3.8	
6	2.9	3.9	
7	3	3.9	
8	3.1	4	
9	3.4	4.1	



**Format Error Bars**

**Vertical Error Bars**

Line Color  
Line Style  
Shadow

**Vertical Error Bars**

Display

Direction

Both  
 Minus  
 Plus

End Style

No Cap  
 Cap

Error Amount

Fixed value: 0.5  
 Percentage: 5.0  
 Standard deviation(s): 1.0  
 Standard error  
 Custom: Specify Value

3. Highlight both STDEVs

**Custom Error Bars**

Positive Error Value  
=Examples!

Negative Error Value  
={1}

OK Cancel

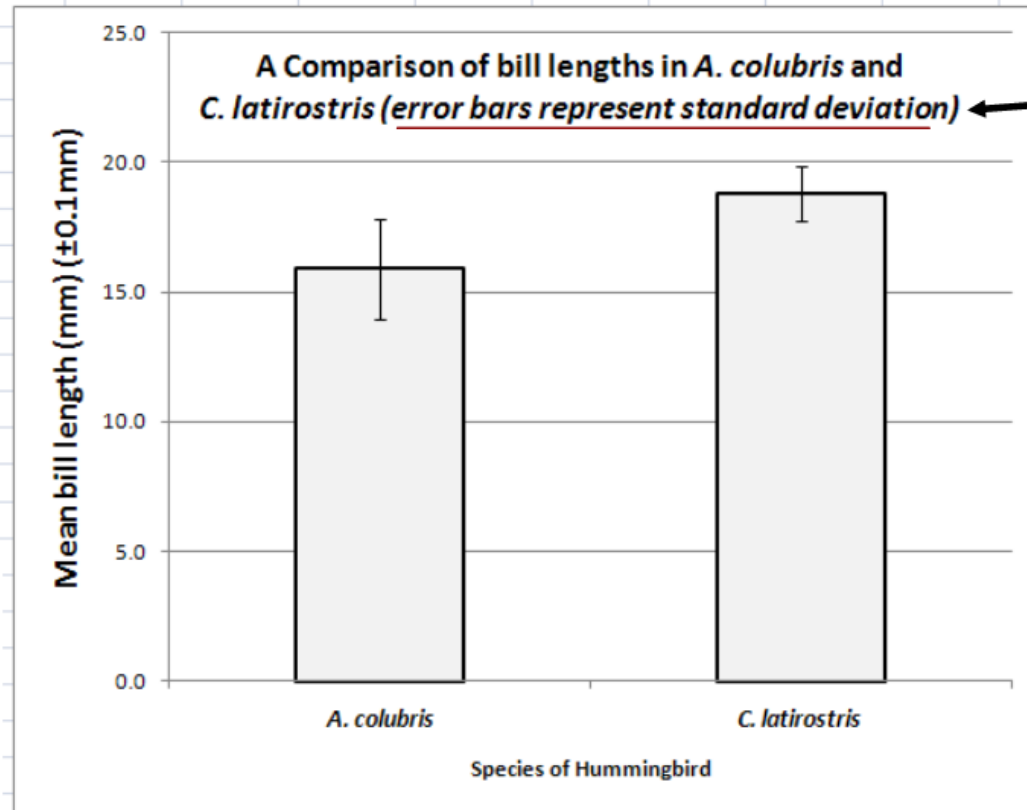
4. Do it again to create the negative error bar

1.

2.

Now each column has an error bar that is its own standard deviation.

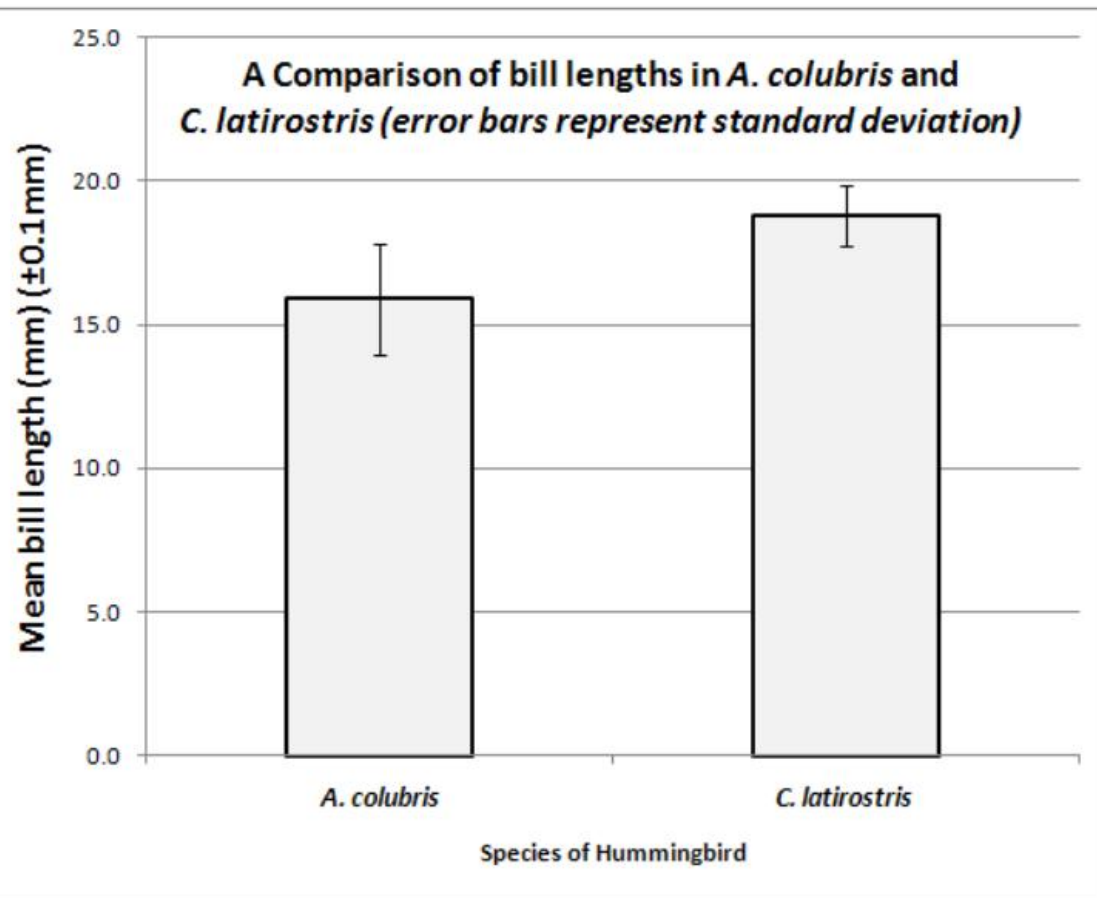
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i>												
2		Bill length (mm) ( $\pm 0.1$ mm)											
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8	5	15.0	19.0										
9	6	16.0	19.0										
10	7	16.0	19.0										
11	8	18.0	20.0										
12	9	18.0	20.0										
13	10	19.0	20.0										
14		<i>A. colubris</i>	<i>C. latirostris</i>										
15	Mean	15.9	18.8										
16	STDEV	1.91	1.03										
17													



To test that it worked, change one value from one column. It should change the mean and STDEV, as well as adjust only one error bar.

Don't forget to 'undo' this test again once you're sure it worked.

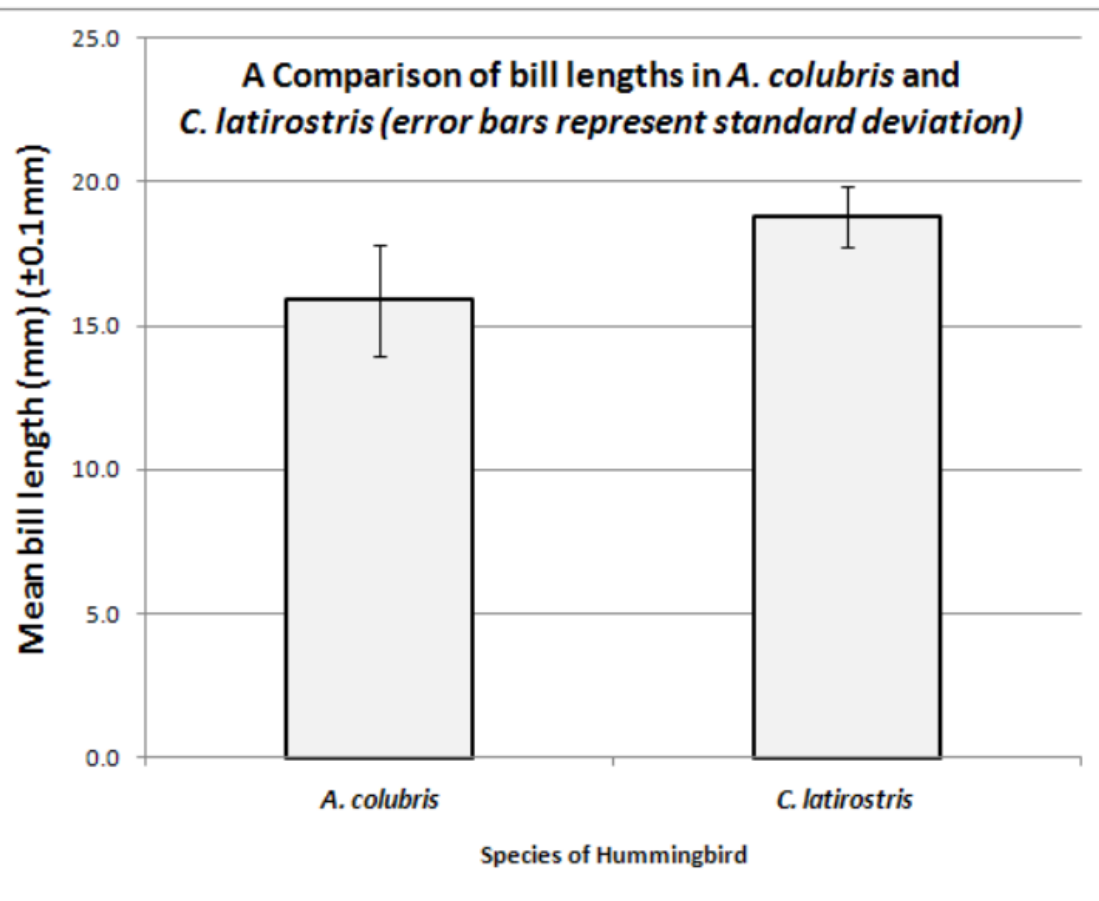
Which sample population has:



A. The longest mean bill?

B. The greatest variability in data?

Which sample population has:



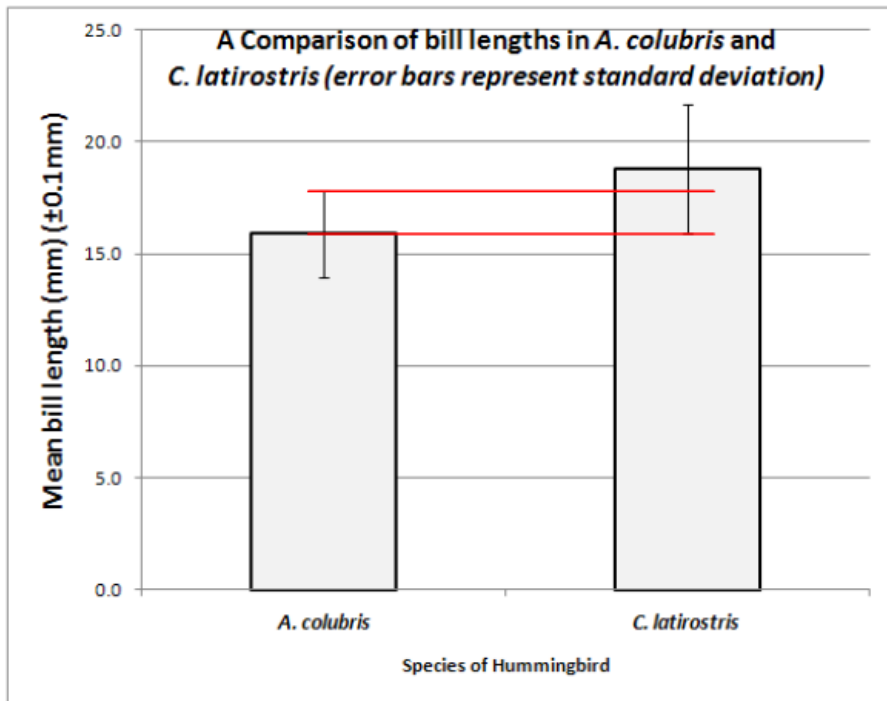
A. The longest mean bill?

*C. latirostris*

B. The greatest variability in data?

*A. colubris*

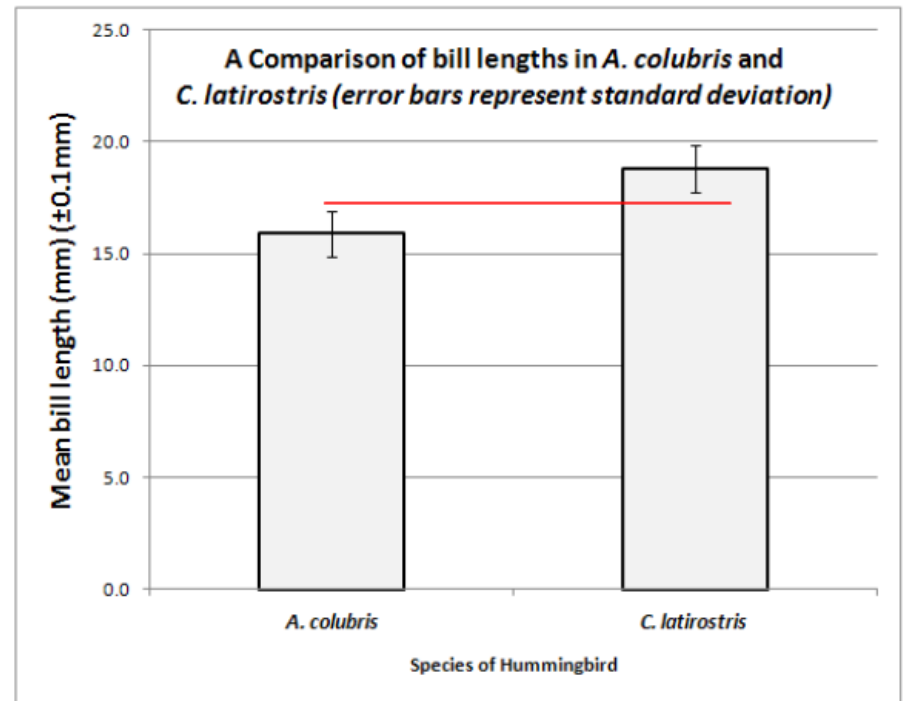
Overlap of error bars gives us a clue as to the significance of the results:



Large overlap  $\therefore$  lots of shared data

Results are **not likely** to be significantly different

(the difference between means is most likely due to chance)

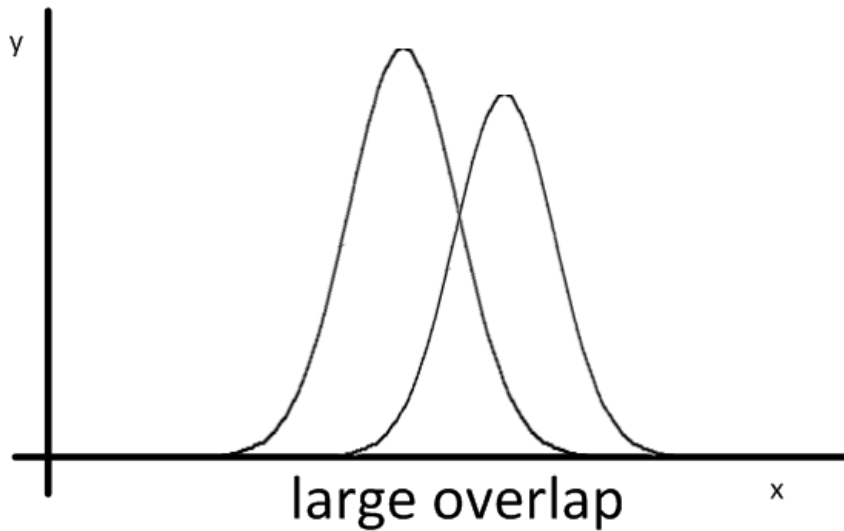


No overlap  $\therefore$  no (or very little) shared data

Results **are likely** to be significantly different

(the difference between means is most likely to be *real*)

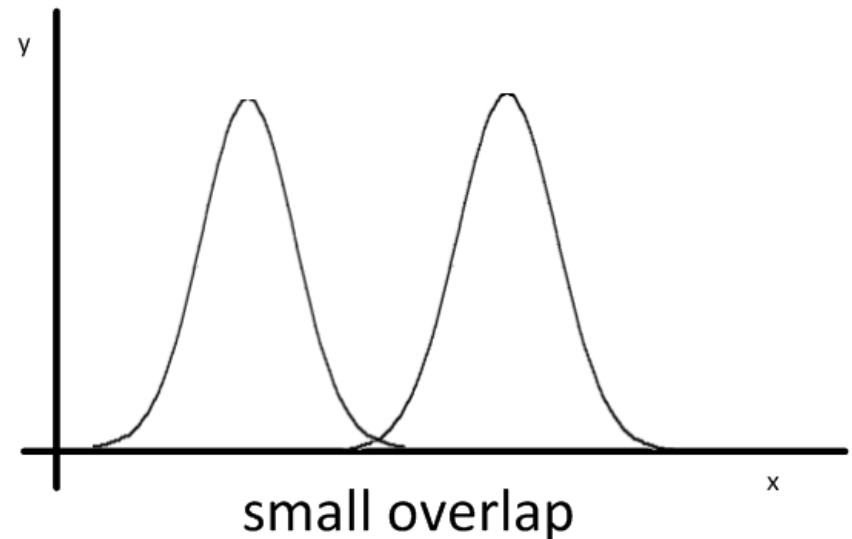
We can see overlap clearly when we plot data as frequency curves:



Large overlap  $\therefore$  lots of shared data

Results are **not likely** to be significantly different

(the difference between means is most likely due to chance)



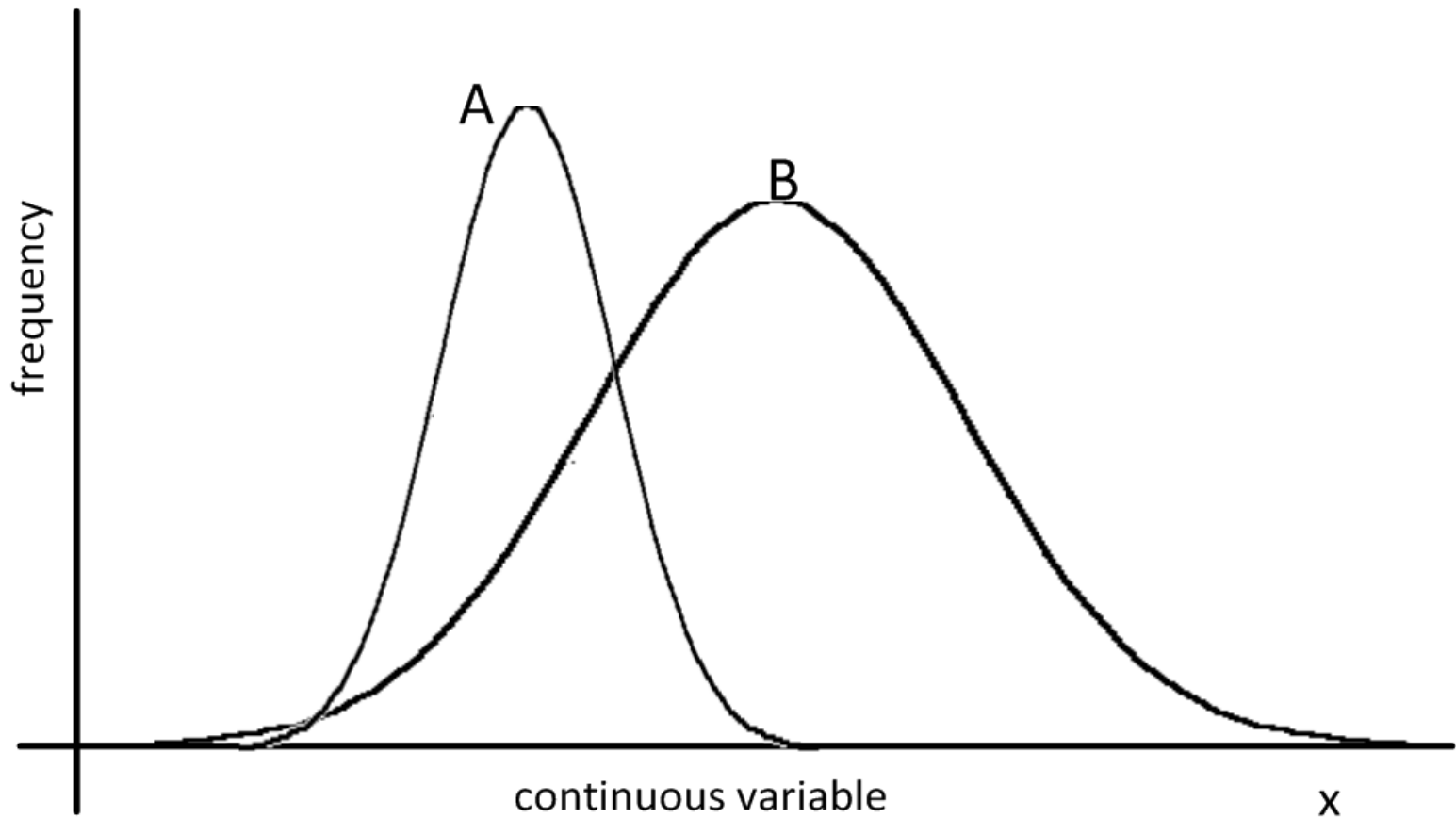
Small overlap  $\therefore$  very little shared data

Results **are likely** to be significantly different

(the difference between means is most likely to be *real*)

Which set of data has...

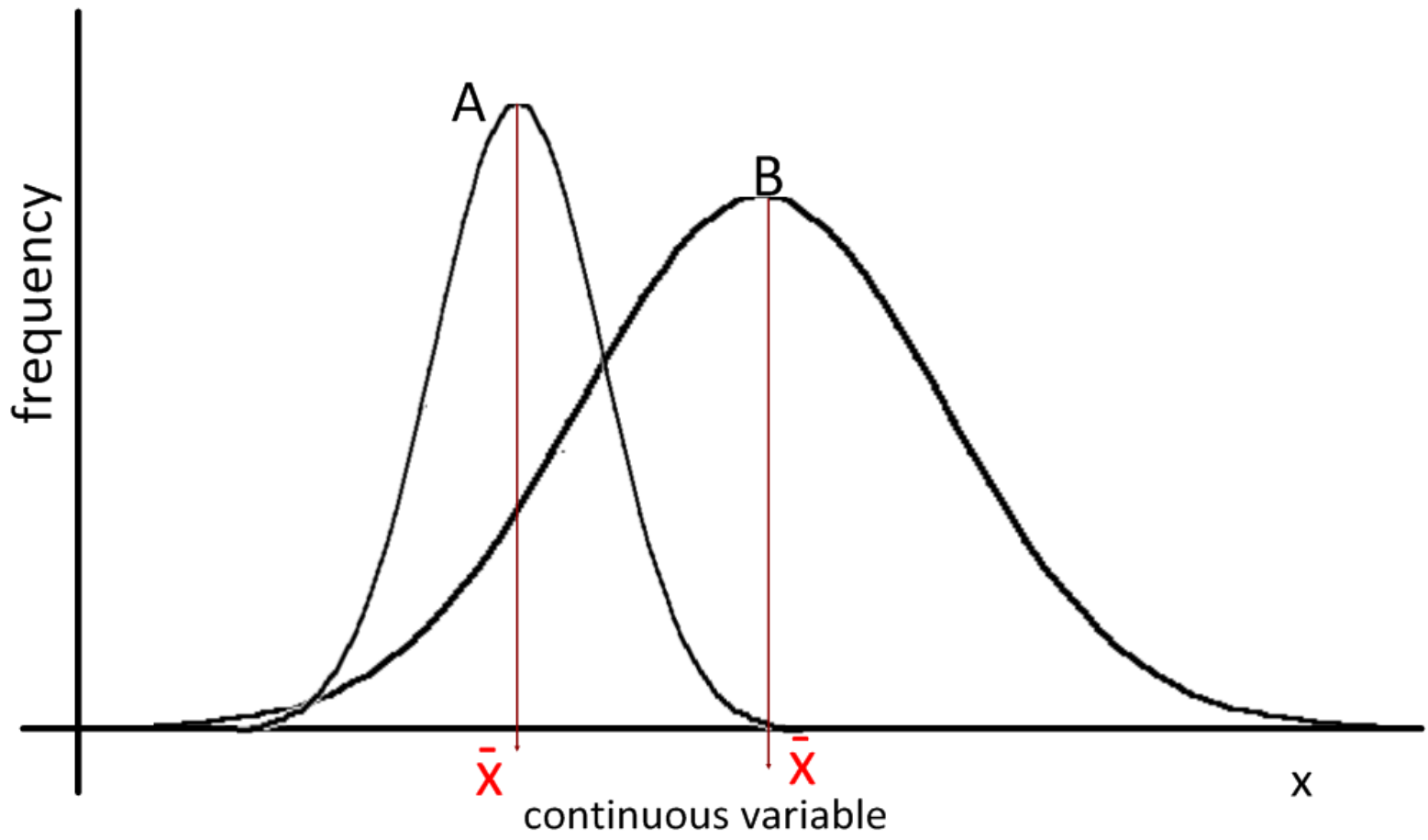
- a. a larger range (high variability)?
- b. a greater standard deviation?
- c. more precise results?
- d. a higher mean?
- e. a higher frequency at the mean?



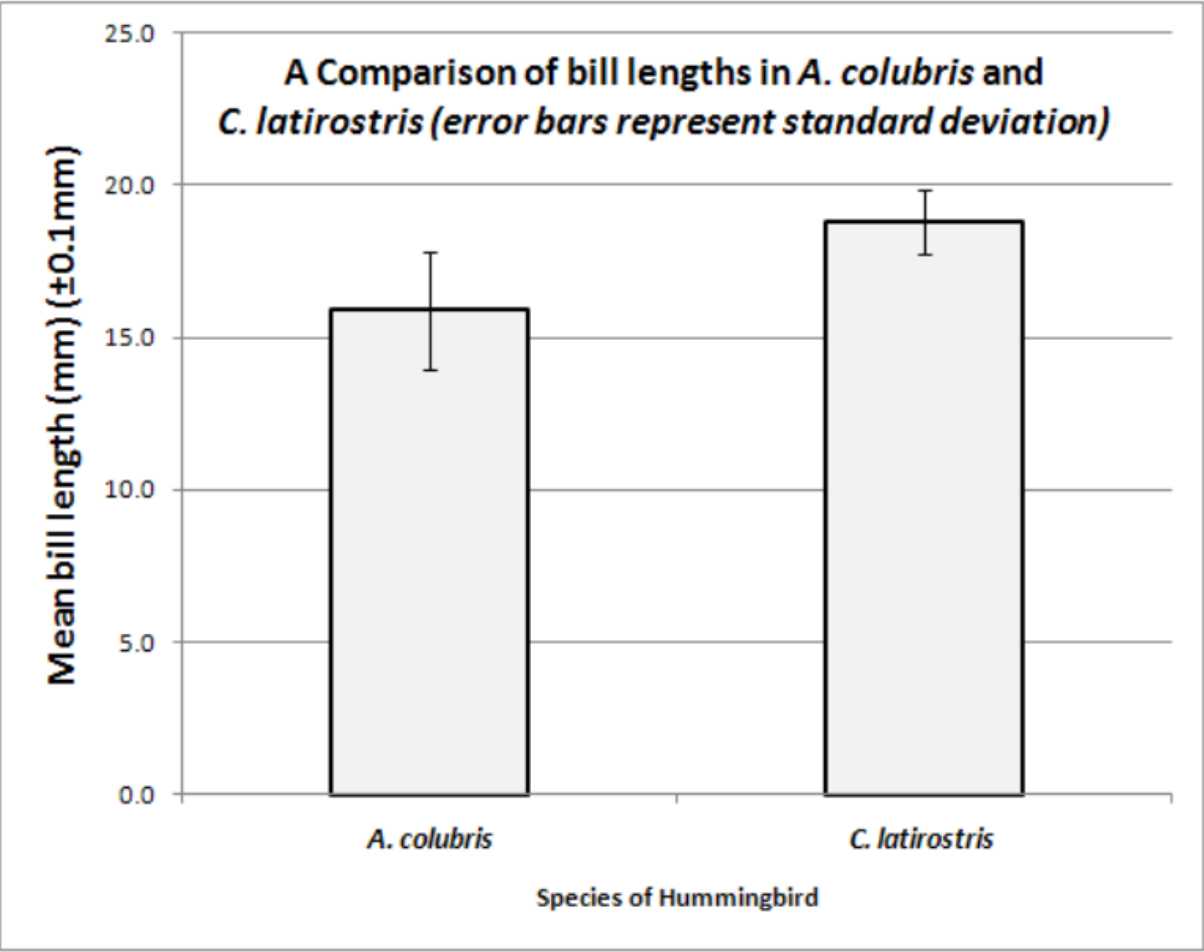


Which set of data has...

- a. a larger range (high variability)? *Set B*
- b. a greater standard deviation? *Set B*
- c. more precise results? *Set A (can be suggested)*
- d. a higher mean? *Set B*
- e. a higher frequency at the mean? *Set A*



To be sure whether our results are significant or not, we need to carry out a statistical test.

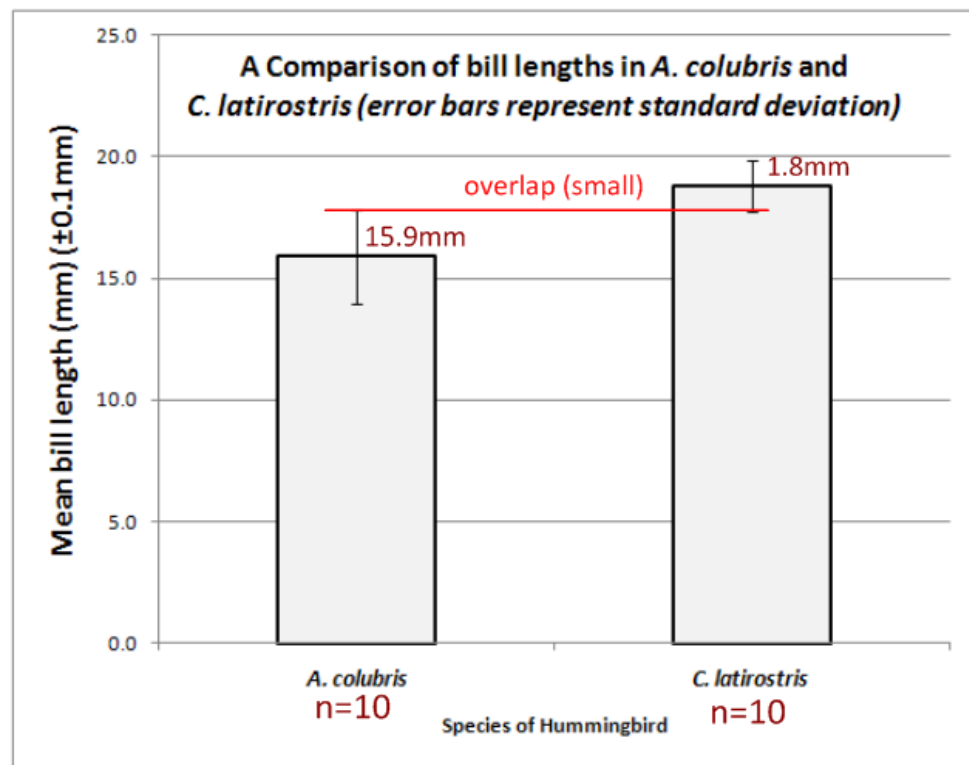


*Is the difference between these means real or the result of chance?*

The **t-test** is a **statistical test** which helps us determine the **significance** of the **difference** between the **means of two populations**.

In other words:

*"Are the means of two populations far enough apart for us to call them truly 'different'?"*



In this example, there seems to be a difference in the bill length between *A. colubris* and *C. latirostris*.

We can also see some overlap in the data, as shown by the error bars.

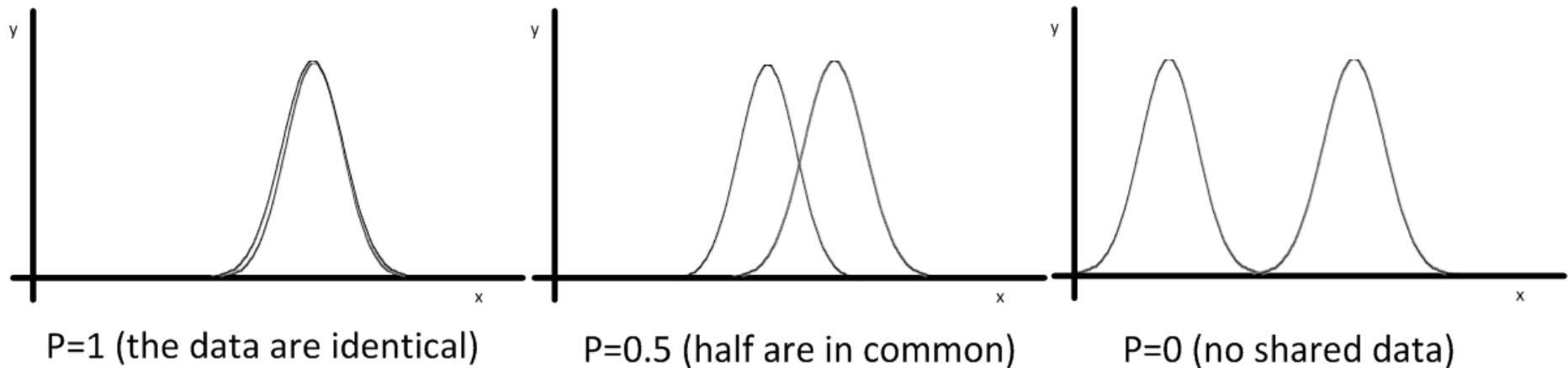
We can use the t-test to test if the difference between the means is large enough to be considered significant.

The **t-test** tells us the **probability** of two data sets being the same.

If **P = 1**, the two sets of data are exactly the same.

If **P = 0**, the two sets of data are not at all the same.

So the higher the value of P, the more the data overlap:



The **smaller the overlap**, the **more significant** our results.

With the **t-test** we always start by stating the **Null Hypothesis**:

$H_0 =$  "There is no significant difference"

This is always the same.

If our t-test instructs us to **accept  $H_0$** , it means that the two population means are **not significantly different**.


If it instructs us to **reject  $H_0$** , then we can say that **there is a significant difference** between the two means.

We can calculate 't' for a pair of data sets and compare it to calculated 'critical values' dependent on a number of pre-determined factors:

How sure do we want to be? 

**Biology:**  
usually 95% confidence  
(or  $P < 0.05$ )

Significance ( $\alpha$ ) (confidence = $1 - \alpha$ )					
<b>P</b>	0.10	0.05	0.025	0.01	0.005
	less confident				more confident
<b><math>\alpha</math></b>	90%	95%	97.5%	99%	99.5%



We can calculate 't' for a pair of data sets and compare it to calculated 'critical values' dependent on a number of pre-determined factors:

How sure do we want to be? ←

Significance ( $\alpha$ ) (confidence =  $1-\alpha$ )

**Biology:**  
usually 95% confidence  
(or  $P < 0.05$ )

P	0.10	0.05	0.025	0.01	0.005
$\alpha$	90%	95%	97.5%	99%	99.5%

less confident → more confident

degrees of freedom  
(total sample size - 2)

- df
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

We can calculate 't' for a pair of data sets and compare it to calculated 'critical values' dependent on a number of pre-determined factors:

How sure do we want to be? 

**Biology:**  
usually 95% confidence  
(or  $P < 0.05$ )

degrees of freedom  
(total sample size - 2)

df	Significance ( $\alpha$ ) (confidence = $1 - \alpha$ )				
	$P$ 0.10 <small>less confident</small>	0.05	0.025	0.01	0.005 <small>more confident</small>
$\alpha$	90%	95%	97.5%	99%	99.5%
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169

critical values



## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

df =

P =

$\therefore$  critical value =

df	Significance ( $\alpha$ ) (confidence = $1-\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.779
5	1.476	2.015	2.571	3.365	4.047
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.358
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.177
11	1.363	1.796	2.201	2.718	3.119
12	1.356	1.782	2.179	2.681	3.071
13	1.350	1.771	2.160	2.650	3.030
14	1.345	1.761	2.145	2.624	2.995
15	1.341	1.753	2.131	2.602	2.965
16	1.337	1.746	2.120	2.583	2.939
17	1.333	1.740	2.110	2.567	2.916
18	1.330	1.734	2.101	2.552	2.895
19	1.328	1.729	2.093	2.539	2.876
20	1.325	1.725	2.086	2.528	2.859
21	1.323	1.721	2.080	2.518	2.844
22	1.321	1.717	2.074	2.508	2.831
23	1.319	1.714	2.069	2.500	2.819
24	1.318	1.711	2.064	2.492	2.808
25	1.316	1.708	2.060	2.485	2.799
26	1.315	1.706	2.056	2.479	2.791
27	1.314	1.703	2.052	2.473	2.784
28	1.313	1.701	2.048	2.467	2.778
29	1.311	1.699	2.045	2.462	2.773
30	1.310	1.697	2.042	2.457	2.769

## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

$$df = (12+13)-2 = 23$$

$P =$

$\therefore$  critical value =

df	Significance ( $\alpha$ ) (confidence = 1- $\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.973
5	1.476	2.015	2.571	3.365	4.477
6	1.440	1.943	2.447	3.143	4.213
7	1.415	1.895	2.365	2.998	4.015
8	1.397	1.860	2.306	2.896	3.858
9	1.383	1.833	2.262	2.821	3.745
10	1.372	1.812	2.228	2.764	3.683
11	1.363	1.796	2.201	2.718	3.634
12	1.356	1.782	2.179	2.681	3.591
13	1.350	1.771	2.160	2.650	3.554
14	1.345	1.761	2.145	2.624	3.521
15	1.341	1.753	2.131	2.602	3.491
16	1.337	1.746	2.120	2.583	3.464
17	1.333	1.740	2.110	2.567	3.439
18	1.330	1.734	2.101	2.552	3.416
19	1.328	1.729	2.093	2.539	3.394
20	1.325	1.725	2.086	2.528	3.374
21	1.323	1.721	2.080	2.518	3.356
22	1.321	1.717	2.074	2.508	3.339
23	1.319	1.714	2.069	2.500	3.323
24	1.318	1.711	2.064	2.492	3.308
25	1.316	1.708	2.060	2.485	3.294
26	1.315	1.706	2.056	2.479	3.281
27	1.314	1.703	2.052	2.473	3.269
28	1.313	1.701	2.048	2.467	3.257
29	1.311	1.699	2.045	2.462	3.246
30	1.310	1.697	2.042	2.457	3.235

## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

$$df = (12+13)-2 = 23$$

$$P = 0.05$$

$\therefore$  critical value =

df	Significance ( $\alpha$ ) (confidence = 1- $\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.971
5	1.476	2.015	2.571	3.365	4.608
6	1.440	1.943	2.447	3.143	4.353
7	1.415	1.895	2.365	2.998	4.215
8	1.397	1.860	2.306	2.896	4.101
9	1.383	1.833	2.262	2.821	4.009
10	1.372	1.812	2.228	2.764	3.930
11	1.363	1.796	2.201	2.718	3.861
12	1.356	1.782	2.179	2.681	3.801
13	1.350	1.771	2.160	2.650	3.747
14	1.345	1.761	2.145	2.624	3.699
15	1.341	1.753	2.131	2.602	3.655
16	1.337	1.746	2.120	2.583	3.615
17	1.333	1.740	2.110	2.567	3.578
18	1.330	1.734	2.101	2.552	3.543
19	1.328	1.729	2.093	2.539	3.510
20	1.325	1.725	2.086	2.528	3.479
21	1.323	1.721	2.080	2.518	3.450
22	1.321	1.717	2.074	2.508	3.423
23	1.319	1.714	2.069	2.500	3.397
24	1.318	1.711	2.064	2.492	3.373
25	1.316	1.708	2.060	2.485	3.350
26	1.315	1.706	2.056	2.479	3.328
27	1.314	1.703	2.052	2.473	3.307
28	1.313	1.701	2.048	2.467	3.287
29	1.311	1.699	2.045	2.462	3.268
30	1.310	1.697	2.042	2.457	3.250

## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

$$df = (12+13)-2 = 23$$

$$P = 0.05$$

$$\therefore \text{critical value} = 1.714$$

df	Significance ( $\alpha$ ) (confidence = 1- $\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.682
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.973
5	1.476	2.015	2.571	3.365	4.608
6	1.440	1.943	2.447	3.143	4.353
7	1.415	1.895	2.365	2.998	4.215
8	1.397	1.860	2.306	2.896	4.101
9	1.383	1.833	2.262	2.821	4.009
10	1.372	1.812	2.228	2.764	3.930
11	1.363	1.796	2.201	2.718	3.861
12	1.356	1.782	2.179	2.681	3.801
13	1.350	1.771	2.160	2.650	3.747
14	1.345	1.761	2.145	2.624	3.699
15	1.341	1.753	2.131	2.602	3.655
16	1.337	1.746	2.120	2.583	3.615
17	1.333	1.740	2.110	2.567	3.579
18	1.330	1.734	2.101	2.552	3.545
19	1.328	1.729	2.093	2.539	3.513
20	1.325	1.725	2.086	2.528	3.483
21	1.323	1.721	2.080	2.518	3.455
22	1.321	1.717	2.074	2.508	3.428
23	1.319	1.714	2.069	2.500	3.402
24	1.318	1.711	2.064	2.492	3.377
25	1.316	1.708	2.060	2.485	3.353
26	1.315	1.706	2.056	2.479	3.330
27	1.314	1.703	2.052	2.473	3.308
28	1.313	1.701	2.048	2.467	3.287
29	1.311	1.699	2.045	2.462	3.267
30	1.310	1.697	2.042	2.457	3.248

## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

$$df = (12+13)-2 = 23$$

$$P = 0.05$$

$\therefore$  critical value = 1.714

$t$  was calculated as 2.15 (this is done for you)

$$t > cv$$
$$2.15 > 1.714$$

If  $t < cv$ , accept  $H_0$

If  $t > cv$ , reject  $H_0$

df	Significance ( $\alpha$ ) (confidence = 1- $\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.779
5	1.476	2.015	2.571	3.365	4.047
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.501
8	1.397	1.860	2.306	2.896	3.358
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.177
11	1.363	1.796	2.201	2.718	3.129
12	1.356	1.782	2.179	2.681	3.091
13	1.350	1.771	2.160	2.650	3.059
14	1.345	1.761	2.145	2.624	3.033
15	1.341	1.753	2.131	2.602	3.011
16	1.337	1.746	2.120	2.583	2.992
17	1.333	1.740	2.110	2.567	2.976
18	1.330	1.734	2.101	2.552	2.962
19	1.328	1.729	2.093	2.539	2.950
20	1.325	1.725	2.086	2.528	2.940
21	1.323	1.721	2.080	2.518	2.931
22	1.321	1.717	2.074	2.508	2.923
23	1.319	1.714	2.069	2.500	2.916
24	1.318	1.711	2.064	2.492	2.910
25	1.316	1.708	2.060	2.485	2.905
26	1.315	1.706	2.056	2.479	2.901
27	1.314	1.703	2.052	2.473	2.897
28	1.313	1.701	2.048	2.467	2.893
29	1.311	1.699	2.045	2.462	2.890
30	1.310	1.697	2.042	2.457	2.887

## Worked example:

A researcher measured the wing spans of 12 red-throat and 13 broadbilled hummingbirds.

$H_0$  = "There is no significant difference"

$$df = (12+13)-2 = 23$$

$$P = 0.05$$

$\therefore$  critical value = 1.714

$t$  was calculated as 2.15 (this is done for you)

$$\begin{array}{ccc} t & & cv \\ 2.15 & > & 1.714 \end{array}$$

If  $t < cv$ , accept  $H_0$

If  $t > cv$ , reject  $H_0$

$\therefore$  reject  $H_0$

*"There is a significant difference between red-throats and broadbills in terms of wing span"*

df	Significance ( $\alpha$ ) (confidence = 1- $\alpha$ )				
	0.10	0.05	0.025	0.01	0.001
1	3.078	6.314	12.706	31.821	63.682
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.771
5	1.476	2.015	2.571	3.365	4.291
6	1.440	1.943	2.447	3.143	3.982
7	1.415	1.895	2.365	2.998	3.747
8	1.397	1.860	2.306	2.896	3.619
9	1.383	1.833	2.262	2.821	3.527
10	1.372	1.812	2.228	2.764	3.450
11	1.363	1.796	2.201	2.718	3.398
12	1.356	1.782	2.179	2.681	3.358
13	1.350	1.771	2.160	2.650	3.328
14	1.345	1.761	2.145	2.624	3.303
15	1.341	1.753	2.131	2.602	3.281
16	1.337	1.746	2.120	2.583	3.263
17	1.333	1.740	2.110	2.567	3.249
18	1.330	1.734	2.101	2.552	3.237
19	1.328	1.729	2.093	2.539	3.227
20	1.325	1.725	2.086	2.528	3.219
21	1.323	1.721	2.080	2.518	3.212
22	1.321	1.717	2.074	2.508	3.206
23	1.319	1.714	2.069	2.500	3.201
24	1.318	1.711	2.064	2.492	3.196
25	1.316	1.708	2.060	2.485	3.192
26	1.315	1.706	2.056	2.479	3.188
27	1.314	1.703	2.052	2.473	3.185
28	1.313	1.701	2.048	2.467	3.182
29	1.311	1.699	2.045	2.462	3.179
30	1.310	1.697	2.042	2.457	3.177

# Why do we reject $H_0$ if $t > cv$ ?

If the calculated value for  $t$  is greater than the critical value, we reject  $H_0$ .

This is because as  $t$  increases, we become more confident that the results are real and not due to chance.

Notice that as the values of  $t$  increase, the values of  $P$  decrease.

If  $t$  is less than the critical value, we are less confident that the difference between the means is significant.

This corresponds with increasing values of  $P$ .

df	Significance ( $\alpha$ ) (confidence = $1-\alpha$ )				
	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314			63.657
2	1.886	2.920			9.925
3	1.638	2.353			5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.789

Decreasing P = more confidence

bigger numbers, more confident

In the exam, you may be given a value for  $t$  and asked to determine whether two sets of data are significantly different.

Use the question to determine the degrees of freedom and confidence limits and compare the calculated value of  $t$  to the table provided.

e.g. 1:

A student measures 16 snail shells on the south side of an island and 15 on the north. She calculates  $t$  as 2.02 and chooses a confidence limit of 95% (0.05). Are her results significantly different?

$H_0 =$  "There is no significant difference"

$df = (\text{total}) - 2 =$

$P =$

$\therefore$  critical value =

confidence limits

df	0.10	0.05	0.025
1	3.078	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
6	1.440	1.943	2.447
7	1.415	1.895	2.365
8	1.397	1.860	2.306
9	1.383	1.833	2.262
10	1.372	1.812	2.228
11	1.363	1.796	2.201
12	1.356	1.782	2.179
13	1.350	1.771	2.160
14	1.345	1.761	2.145
15	1.341	1.753	2.131
16	1.337	1.746	2.120
17	1.333	1.740	2.110
18	1.330	1.734	2.101
19	1.328	1.729	2.093
20	1.325	1.725	2.086
21	1.323	1.721	2.080
22	1.321	1.717	2.074
23	1.319	1.714	2.069
24	1.318	1.711	2.064
25	1.316	1.708	2.060
26	1.315	1.706	2.056
27	1.314	1.703	2.052
28	1.313	1.701	2.048
29	1.311	1.699	2.045
30	1.310	1.697	2.042
40	1.303	1.684	2.021
50	1.299	1.676	2.009
60	1.296	1.671	2.000
70	1.294	1.667	1.994



In the exam, you may be given a value for  $t$  and asked to determine whether two sets of data are significantly different.

Use the question to determine the degrees of freedom and confidence limits and compare the calculated value of  $t$  to the table provided.

e.g. 1:

A student measures 16 snail shells on the south side of an island and 15 on the north. She calculates  $t$  as 1.61 and chooses a confidence limit of 95% (0.05). Are her results significantly different?

$H_0$  = "There is no significant difference"

$$df = (\text{total}) - 2 = (16 + 15) - 2 = 29$$

$$P = 0.05$$

$$\therefore \text{critical value} = 1.699 \quad \begin{matrix} t & & cv \\ 1.61 & < & 1.699 \end{matrix}$$

$\therefore$  accept  $H_0$

"There is a *no significant difference* between north and south-side snails in terms of shell size"

confidence limits

df	0.10	0.05	0.025
1	3.078	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
6	1.440	1.943	2.447
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70	1.294	1.667	1.994

In the exam, you may be given a value for  $t$  and asked to determine whether two sets of data are significantly different.

Use the question to determine the degrees of freedom and confidence limits and compare the calculated value of  $t$  to the table provided.

e.g. 2:

A student measures the resting heart rates of 10 swimmers and 12 non-swimmers. He calculates  $t$  as 3.65 and chooses a confidence limit of 95% (0.05). Are his results significantly different?

confidence limits

df	0.10	0.05	0.025
1	3.078	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
6	1.440	1.943	2.447
7	1.415	1.895	2.365
8	1.397	1.860	2.306
9	1.383	1.833	2.262
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In the exam, you may be given a value for  $t$  and asked to determine whether two sets of data are significantly different.

Use the question to determine the degrees of freedom and confidence limits and compare the calculated value of  $t$  to the table provided.

e.g. 2:

A student measures the resting heart rates of 10 swimmers and 12 non-swimmers. He calculates  $t$  as 3.65 and chooses a confidence limit of 95% (0.05). Are his results significantly different?

$H_0$  = "There is no significant difference"

$$df = (\text{total}) - 2 = (10 + 12) - 2 = 20$$

$$P = 0.05$$

$$\therefore \text{critical value} = 1.725$$

$$\begin{array}{ccc} t & & cv \\ 3.65 & > & 1.699 \end{array}$$

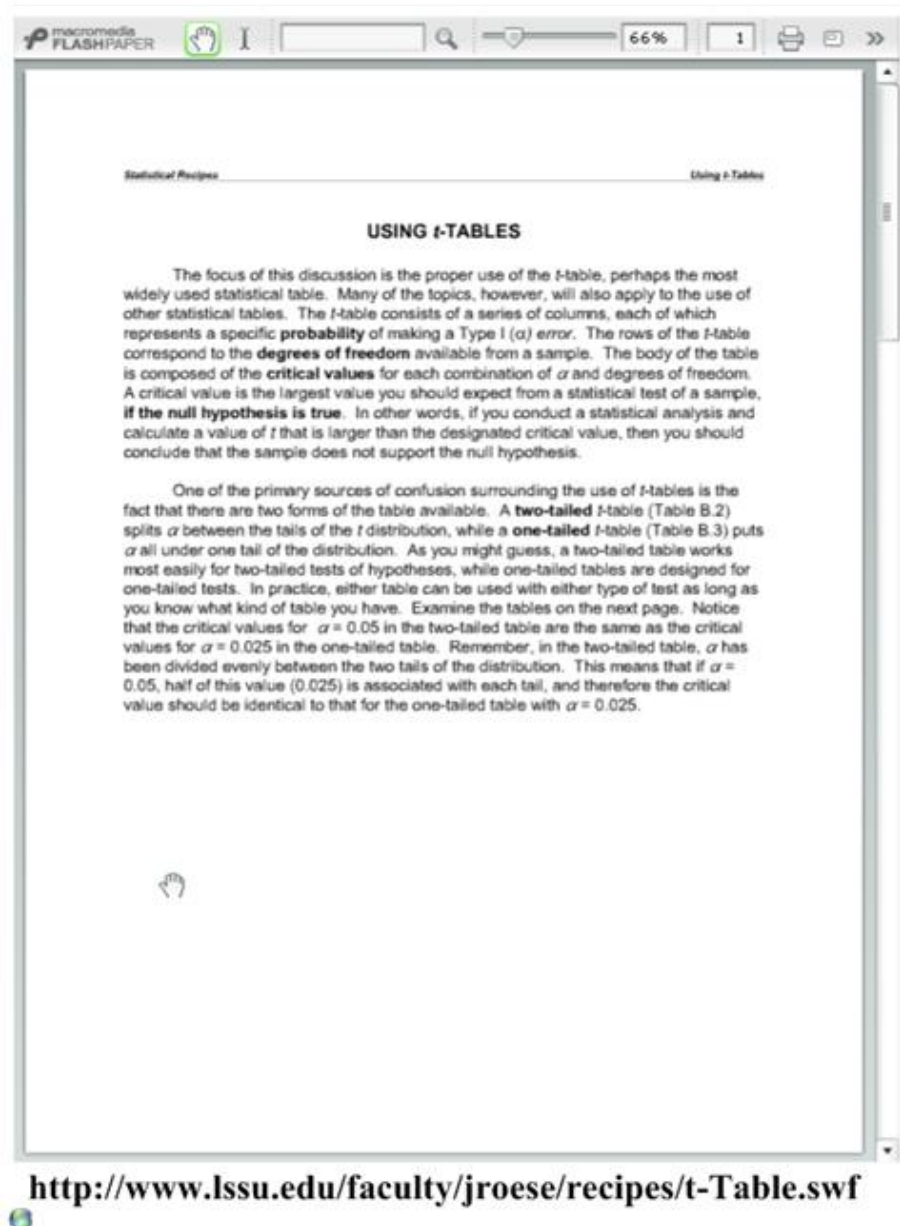
$\therefore$  reject  $H_0$

*"There is a significant difference between red-throats and broadbills in terms of wing span"*

confidence limits

df	0.10	0.05	0.025
1	3.078	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
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50	1.299	1.676	2.009
60	1.296	1.671	2.000
70	1.294	1.667	1.994

# Some more awesome t-test resources:



The screenshot shows a web browser window with a PDF document titled "Using t-Tables". The document content is as follows:

Statistical Recipes Using t-Tables

## USING t-TABLES

The focus of this discussion is the proper use of the t-table, perhaps the most widely used statistical table. Many of the topics, however, will also apply to the use of other statistical tables. The t-table consists of a series of columns, each of which represents a specific **probability** of making a Type I ( $\alpha$ ) error. The rows of the t-table correspond to the **degrees of freedom** available from a sample. The body of the table is composed of the **critical values** for each combination of  $\alpha$  and degrees of freedom. A critical value is the largest value you should expect from a statistical test of a sample, **if the null hypothesis is true**. In other words, if you conduct a statistical analysis and calculate a value of  $t$  that is larger than the designated critical value, then you should conclude that the sample does not support the null hypothesis.

One of the primary sources of confusion surrounding the use of t-tables is the fact that there are two forms of the table available. A **two-tailed** t-table (Table B.2) splits  $\alpha$  between the tails of the  $t$  distribution, while a **one-tailed** t-table (Table B.3) puts  $\alpha$  all under one tail of the distribution. As you might guess, a two-tailed table works most easily for two-tailed tests of hypotheses, while one-tailed tables are designed for one-tailed tests. In practice, either table can be used with either type of test as long as you know what kind of table you have. Examine the tables on the next page. Notice that the critical values for  $\alpha = 0.05$  in the two-tailed table are the same as the critical values for  $\alpha = 0.025$  in the one-tailed table. Remember, in the two-tailed table,  $\alpha$  has been divided evenly between the two tails of the distribution. This means that if  $\alpha = 0.05$ , half of this value (0.025) is associated with each tail, and therefore the critical value should be identical to that for the one-tailed table with  $\alpha = 0.025$ .

<http://www.lssu.edu/faculty/jroese/recipes/t-Table.swf>

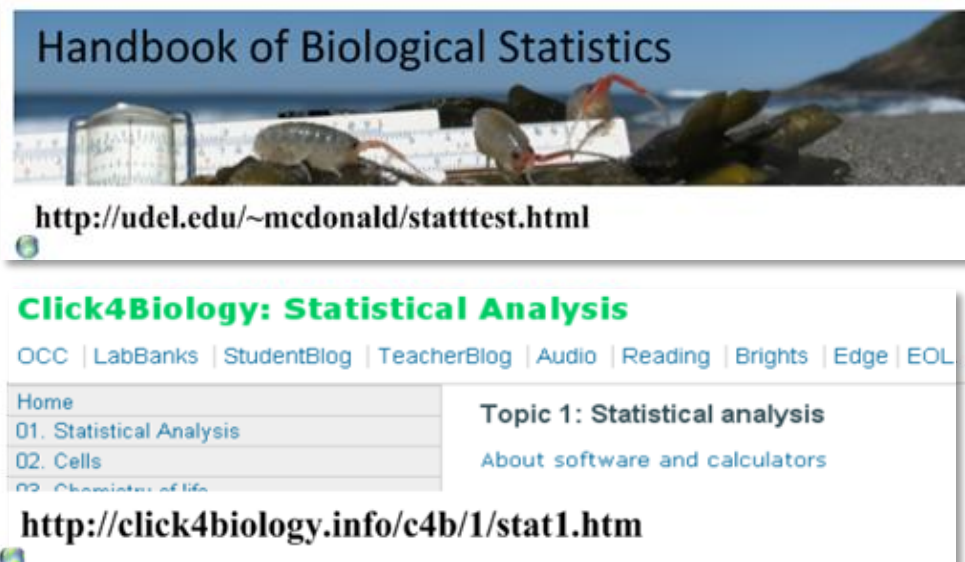


The screenshot shows a presentation slide titled "The T-Test, by Geoff Browne". The slide features a pink background with stick figures and the text:

Are our results reliable enough to support a conclusion?

Geoff Browne  
Anglo-European School  
Essex, UK

<http://www.slideshare.net/gurustip/the-ttest-by-geoff-browne>



The screenshot shows a website titled "Handbook of Biological Statistics". The website features a banner image of a beach scene with a crab and a seashell. The URL is:

<http://udel.edu/~mcdonald/stattest.html>

## Click4Biology: Statistical Analysis

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- 01. Statistical Analysis
- 02. Cells
- 03. Chemistry of life

Topic 1: Statistical analysis

About software and calculators

<http://click4biology.info/c4b/1/stat1.htm>

# Carrying out the T-test in Excel

(This will be useful for investigations)

The screenshot shows the Microsoft Excel interface with the 'More Functions' menu open. The 'Statistical' category is selected, and the 'TTEST' function is highlighted. A tooltip for 'TTEST' is visible, explaining its syntax and purpose: 'TTEST(array1,array2,tails,type) Returns the probability associated with a Student's t-Test. Press F1 for more help.' The spreadsheet data is as follows:

Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i>			
Bill length (mm) ( $\pm 0.1$ mm)			
n	<i>A. colubris</i>	<i>C. latirostris</i>	
1	13.0	17.0	
2	14.0	18.0	
3	15.0	18.0	
4	15.0	18.0	
5	15.0	19.0	
6	16.0	19.0	
7	16.0	19.0	
8	18.0	20.0	
9	18.0	20.0	
10	19.0	20.0	
	<i>A. colubris</i>	<i>C. latirostris</i>	
Mean	15.9	18.8	
STDEV	1.91	1.03	
t-test			
P=			

Excel can calculate P directly.

TTEST

# Carrying out the T-test in Excel

(This will be useful for investigations)

Hummingbirds.xlsx - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Add-Ins Nitro PDF

Insert Function AutoSum Recently Used Financial Logical Text Date & Time Lookup & Reference Math & Trig More Functions Name Manager Define Name Use in Formula Create from Selection Defined Names Trace P Trace D Remove

Function Library

TTEST  $=TTEST(B4:B13,C4:C13,2,2)$

	A	B	C	D	E	F	G	H	I	J	K
1	<b>Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i></b>										
2		<b>Bill length (mm) (<math>\pm 0.1</math>mm)</b>									
3	n	<i>A. colubris</i>	<i>C. latirostris</i>								
4	1	13.0	17.0								
5	2	14.0	18.0								
6	3	15.0	18.0								
7	4	15.0	18.0								
8	5	15.0	19.0								
9	6	16.0	19.0								
10	7	16.0	19.0								
11	8	18.0	20.0								
12	9	18.0	20.0								
13	10	19.0	20.0								
14		<i>A. colubris</i>	<i>C. latirostris</i>								
15	Mean	15.9	18.8								
16	STDEV	1.91	1.03								
17	<b>t-test</b>										
18	P=	C4:C13,2,2)									
19											
20											

**Function Arguments**

TTEST

Array1: B4:B13 = {13;14;15;15;15;16;16;18;18;19}

Array2: C4:C13 = {17;18;18;18;19;19;19;20;20;20}

Tails: 2 = 2

Type: 2 = 2

= 0.000514697

Returns the probability associated with a Student's t-Test.

Array2 is the second data set.

Formula result = 0.000514697

[Help on this function](#)

OK Cancel

Data set A

Data set B

Use 2 tails and type 2 for a basic t-test comparing two sets of data

# Carrying out the T-test in Excel

## Interpreting the results

(This will be useful for investigations)

	A	B	C	D	E
1	<b>Comparing bill length in <i>A. colubris</i> and <i>C. latirostris</i></b>				
2		<b>Bill length (mm) (<math>\pm 0.1\text{mm}</math>)</b>			
3	n	<i>A. colubris</i>	<i>C. latirostris</i>		
4	1	13.0	17.0		
5	2	14.0	18.0		
6	3	15.0	18.0		
7	4	15.0	18.0		
8	5	15.0	19.0		
9	6	16.0	19.0		
10	7	16.0	19.0		
11	8	18.0	20.0		
12	9	18.0	20.0		
13	10	19.0	20.0		
14		<i>A. colubris</i>	<i>C. latirostris</i>		
15	Mean	15.9	18.8		
16	STDEV	1.91	1.03		
17	<b>t-test</b>				
18	Ho = There is no significant difference				
19	P=	0.000514697			
20					
21	<b>P &lt; 0.05</b>				
22	Therefore reject H <sub>0</sub>				
23	There is a significant difference in bill length				
24	between <i>A. colubris</i> and <i>C. latirostris</i>				
25					

Remember: the smaller the value of P, the greater the confidence that the difference between the means is significant.

So if we are jumping directly to a calculation of P, we use this rule:

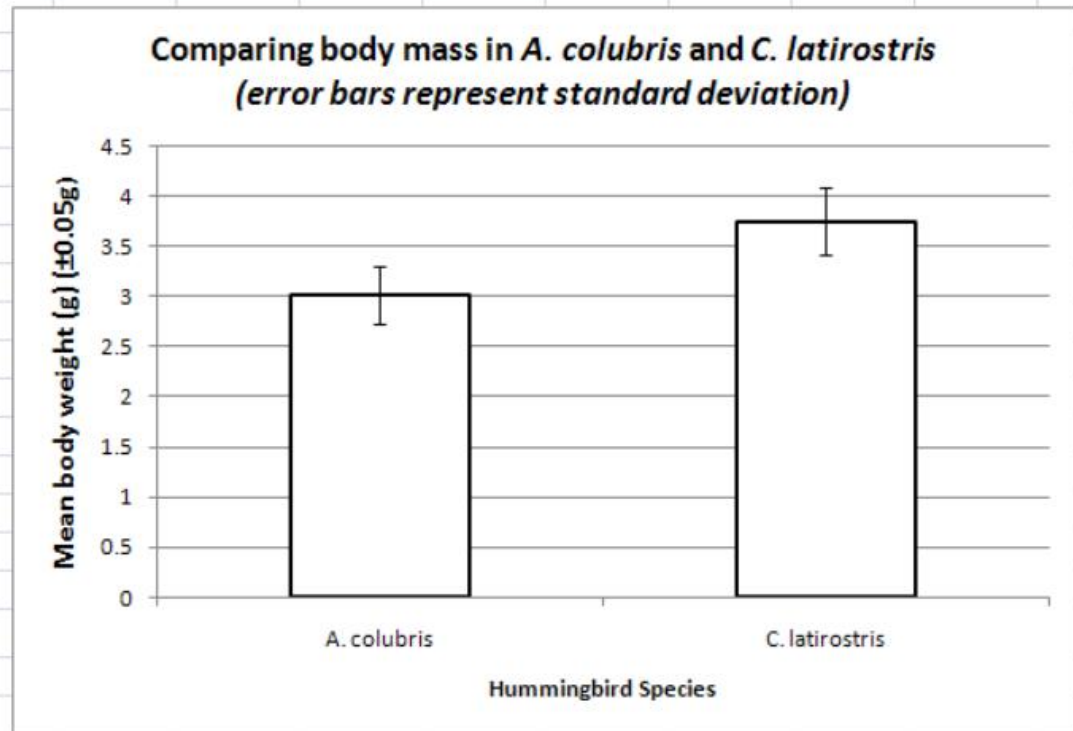
**If  $P < 0.05$ , reject  $H_0$**

(we are more than 95% confident that the difference is not due to chance)

P is much smaller than 0.05

# How about the comparison in body weights?

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	<b>Comparing body weight in <i>A. colubris</i> and <i>C. latirostris</i></b>												
2	<b>Body weight (g) (<math>\pm 0.05g</math>)</b>												
3	n	<i>A. colubris</i>	<i>C. latirostris</i>										
4	1	2.7	3.1										
5	2	2.8	3.4										
6	3	2.8	3.5										
7	4	2.9	3.7										
8	5	2.9	3.8										
9	6	2.9	3.9										
10	7	3	3.9										
11	8	3.1	4										
12	9	3.4	4.1										
13	10	3.6	4.1										
14		<i>A. colubris</i>	<i>C. latirostris</i>										
15	Mean	3.01	3.75										
16	STDEV	0.284604989	0.327448045										
17	t-test												
18	$H_0$	= There is no significant difference											
19	P=	0.0000399											
20													
21	<b>P &lt; 0.05</b>												
22	Therefore reject $H_0$												
23													
24	There is a signiifcant difference in body weight												
25	between <i>A. colubris</i> and <i>C. latirostris</i>												
26													
27													
28													





# Cat Fleas vs Dog Fleas

"A Comparison of Jump Performances of the Dog Flea, *Ctenocephalides canis* (Curtis, 1826) and the Cat Flea, *Ctenocephalides felis felis* (Bouche, 1835)," M.C. Cadiergues, C. Joubert, and M. Franc, *Veterinary Parasitology*, vol. 92, no. 3, October 1, 2000, pp. 239-41.



Winner of the 2008 Ig Nobel prize for Biology.

<http://www.youtube.com/watch?v=fJEZg4QN760>

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RESEARCH** 

Research that makes people LAUGH and then THINK

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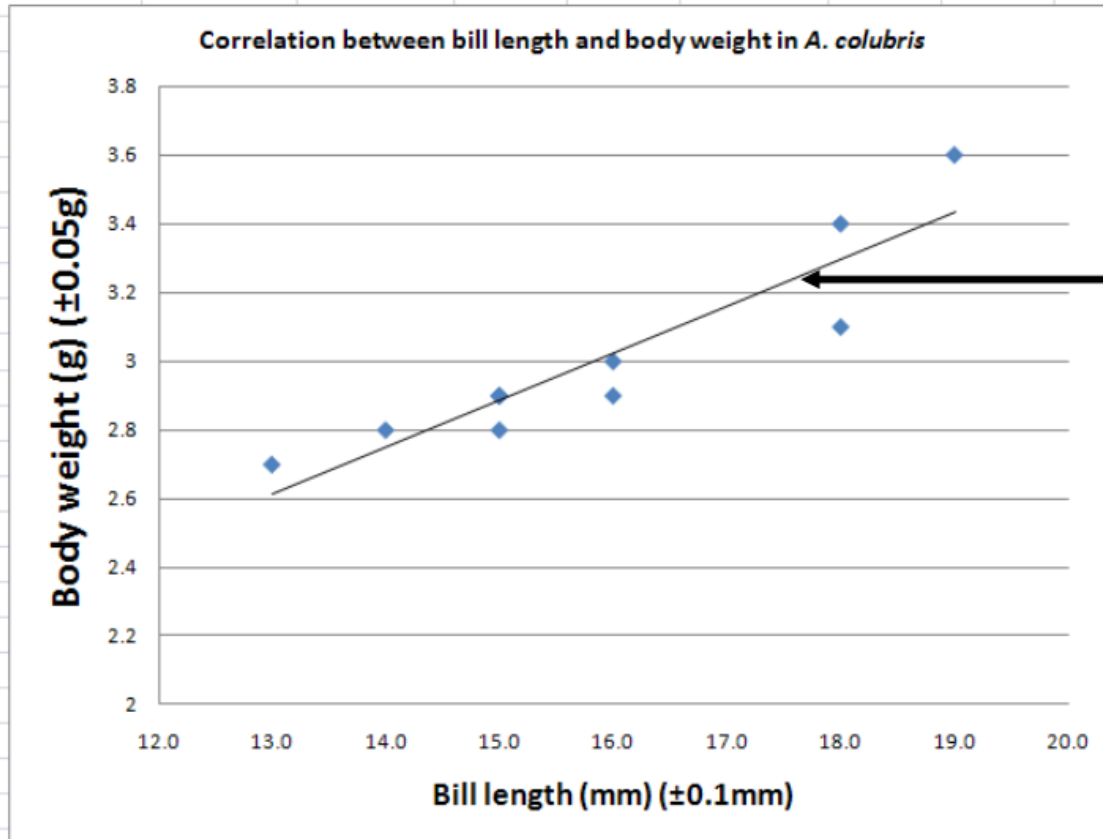
Search

go

<http://improbable.com/ig/ig-pastwinners.html>

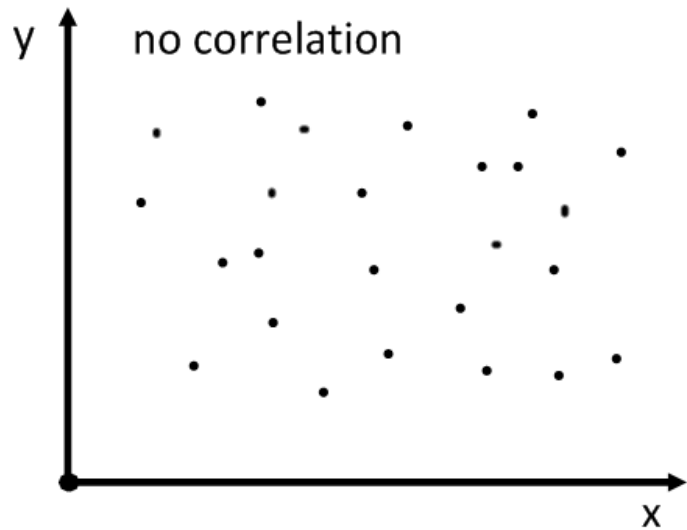
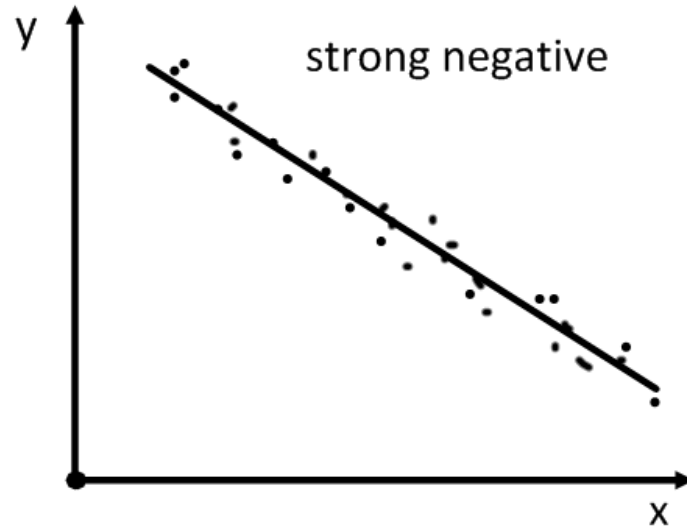
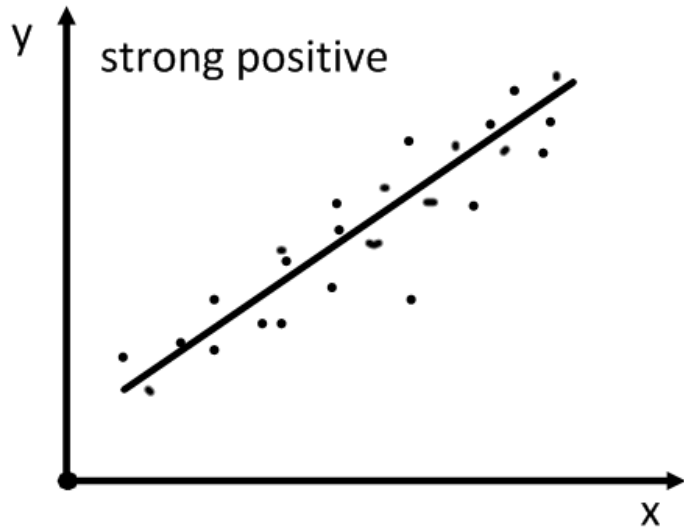
# Correlations can suggest relationships between sets of data:

	A	B	C	D	E	F	G	H	I	J	K
1	Comparing bill length and body weight in <i>A. colubris</i>										
2											
3	bill length	13.0	14.0	15.0	15.0	15.0	16.0	16.0	18.0	18.0	19.0
4	weight	2.7	2.8	2.8	2.9	2.9	2.9	3	3.1	3.4	3.6
5											



In this set of data, there is a strong positive correlation between bill length and body weight.

# Examples of correlations:



# But correlations **do not prove causality!**

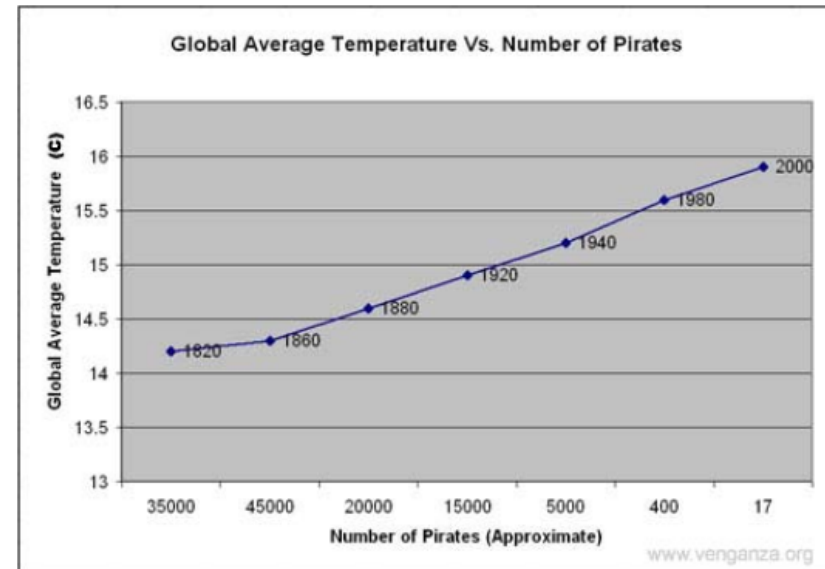
If a correlation exists, **further research** is needed to determine whether or not the relationship is causal.

In the investigation, one would have **independent**, **dependent** and **carefully controlled variables**.

Some causal relationships:

- Temperature vs enzyme activity
- Concentration vs rate of diffusion
- CO<sub>2</sub> concentration vs rate of photosynthesis

By manipulating the independent variable, we can measure a change in the dependent variable.

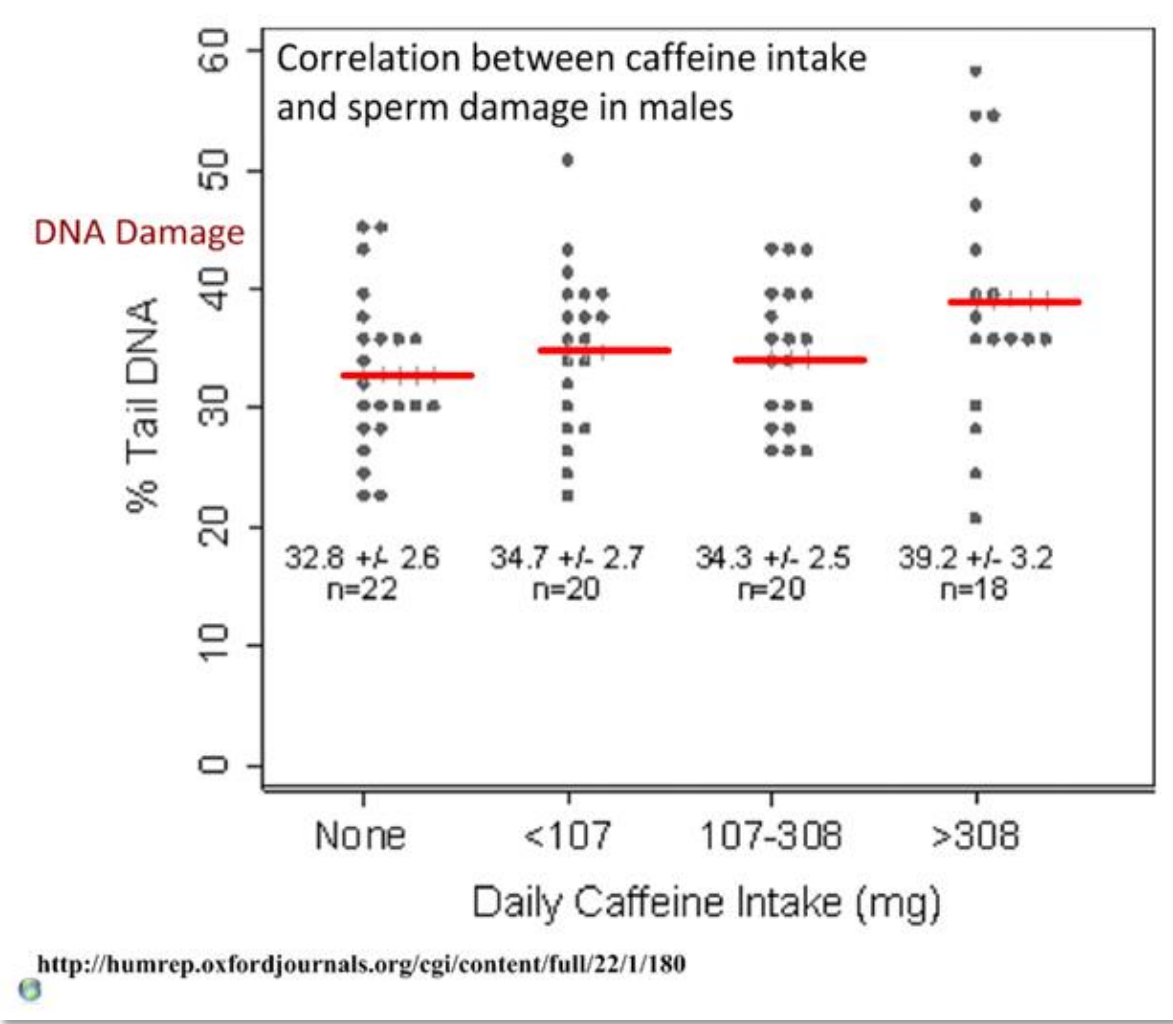


Clearly no causal relationship!

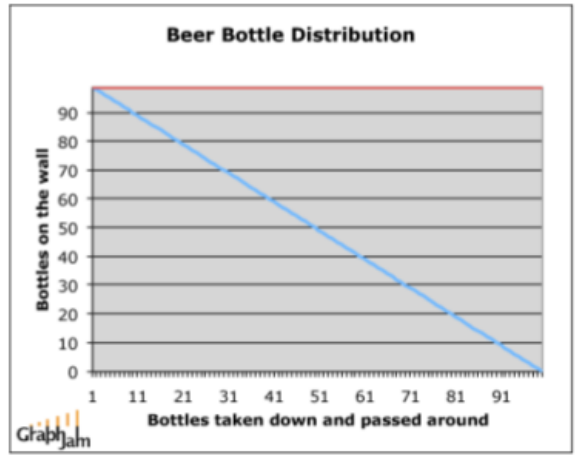
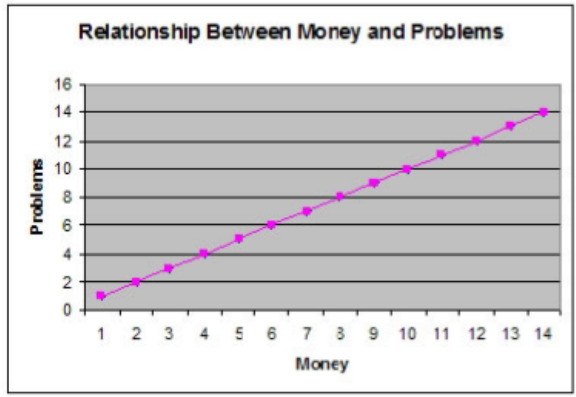
<http://www.venganza.org/about/open-letter/>



# Go easy on the coffee, boys!



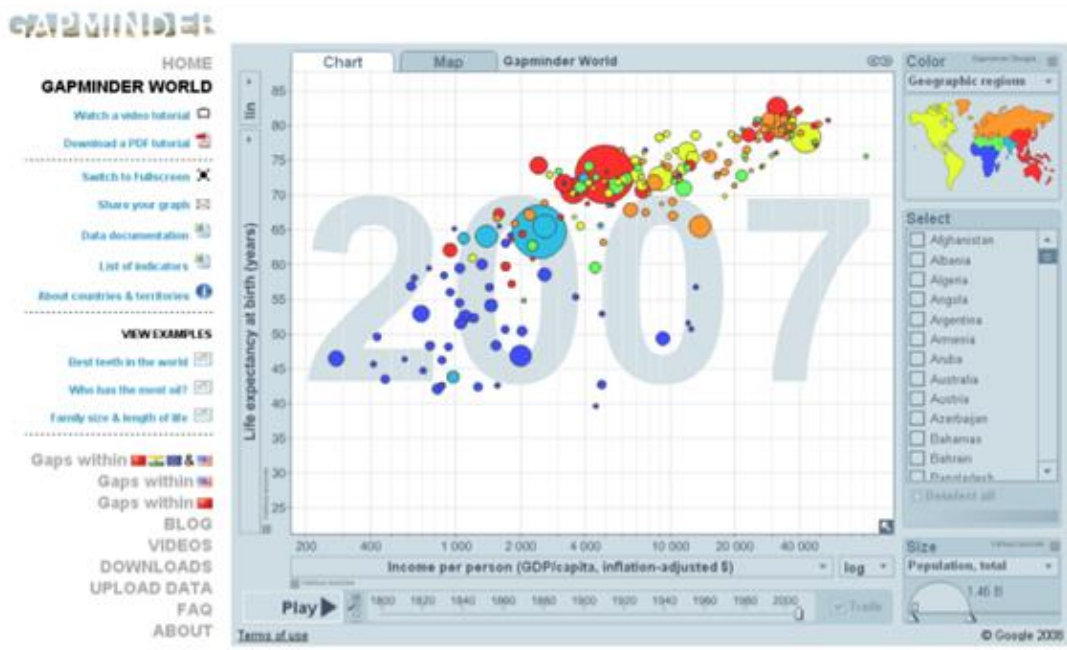
## Funny graphs:



<http://graphjam.com/>

How could you test the causality of this relationship?

Try out this for amazing human population statistics:



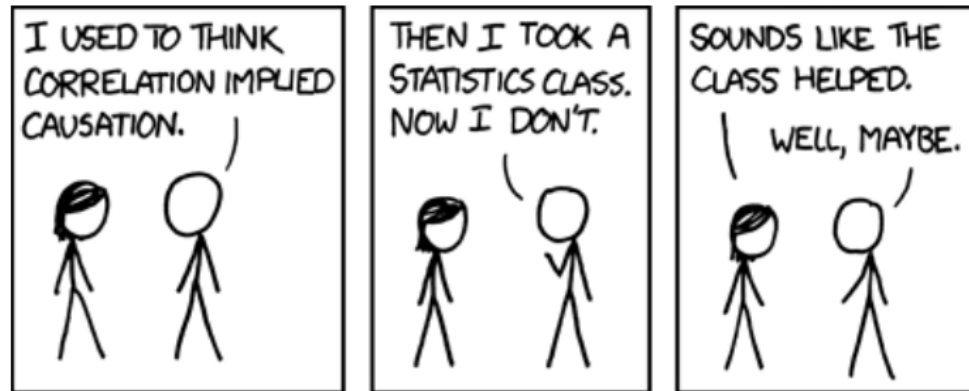
<http://graphs.gapminder.org/>

See the talk here:

Hans Rosling: No more boring data: TEDTalks



<http://www.youtube.com/watch?v=hVimVzgtD6w>



<http://www.xkcd.com/552/>



For more IB Biology resources:  
<http://sciencevideos.wordpress.com>