Statistical Analysis

Stephen Taylor
Bandung International School

Image: 'Hummingbird'
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

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

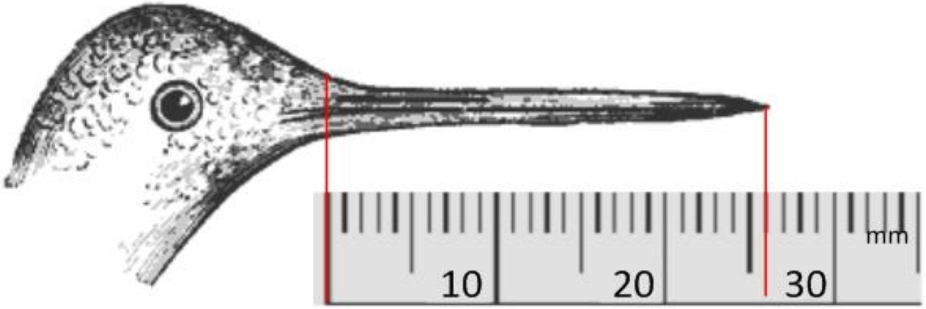
3.9g (± 0.1g) for a digital measuring device

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

26mm (± 1mm)

(± 0.5mm at both ends)

Analogue measurements are usually (±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 (± 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	**Comparing bill length in *A. colubris* and *C. latirostris***				
2		**Bill length (mm) (± 0.1mm)**			
3	n	*A. colubris*	*C. latirostris*		
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		*A. colubris*	*C. latirostris*		
15	**Mean**				
16	STDEV				
17					

Give the raw data table a title

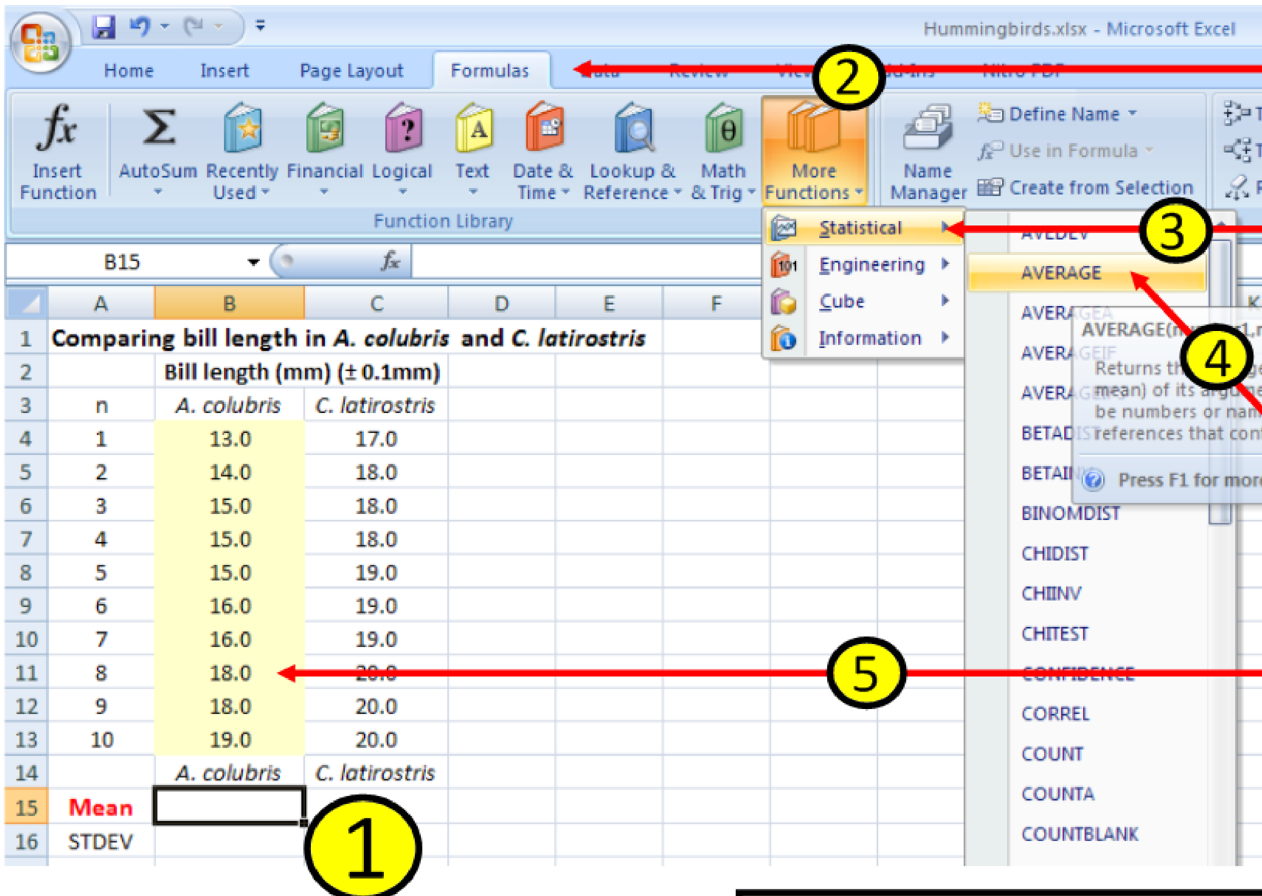
Include uncertainty

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



Select this box

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

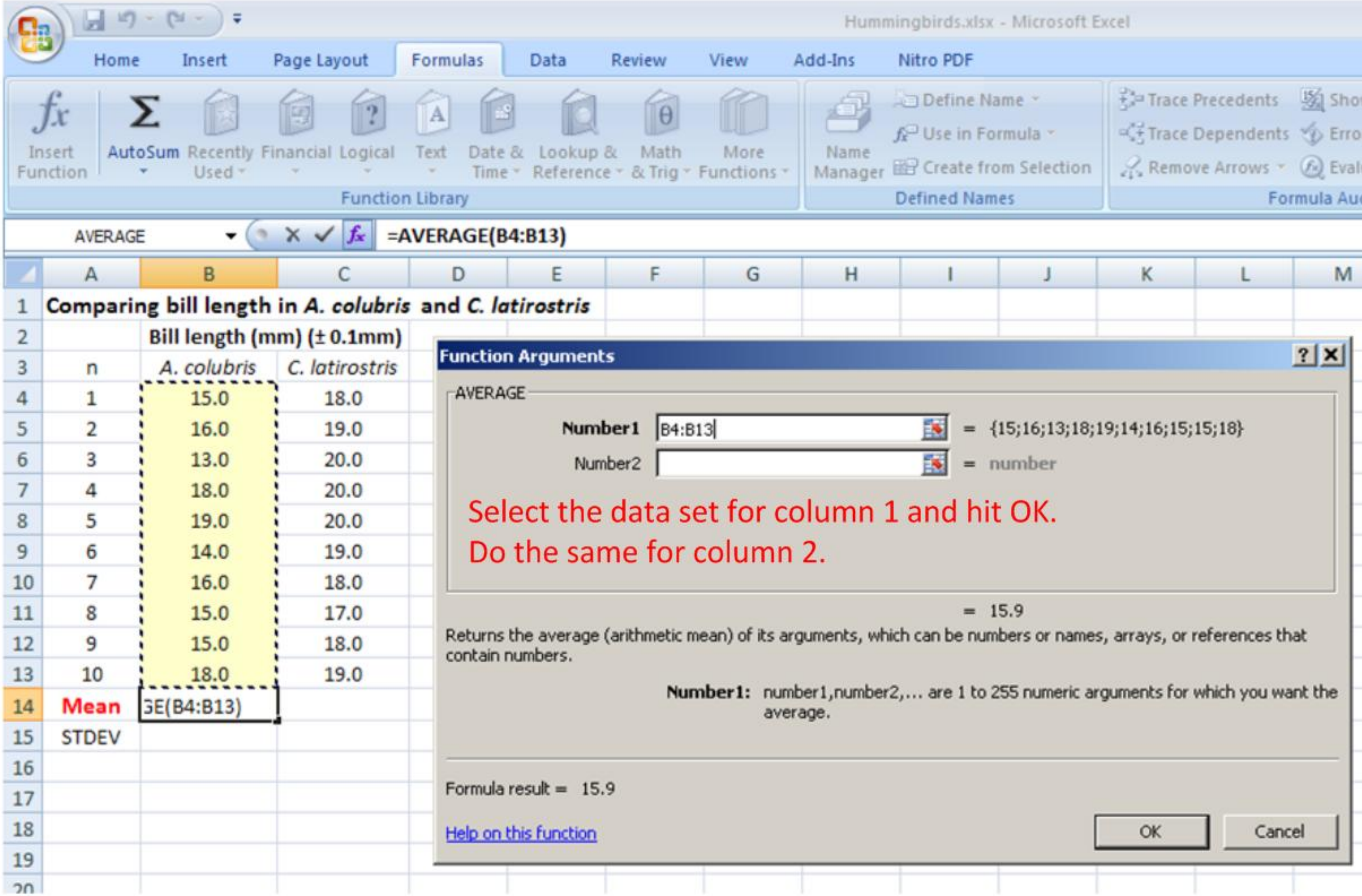
'More Functions'
'Statistical'

To find the arithmetic mean, select AVERAGE.

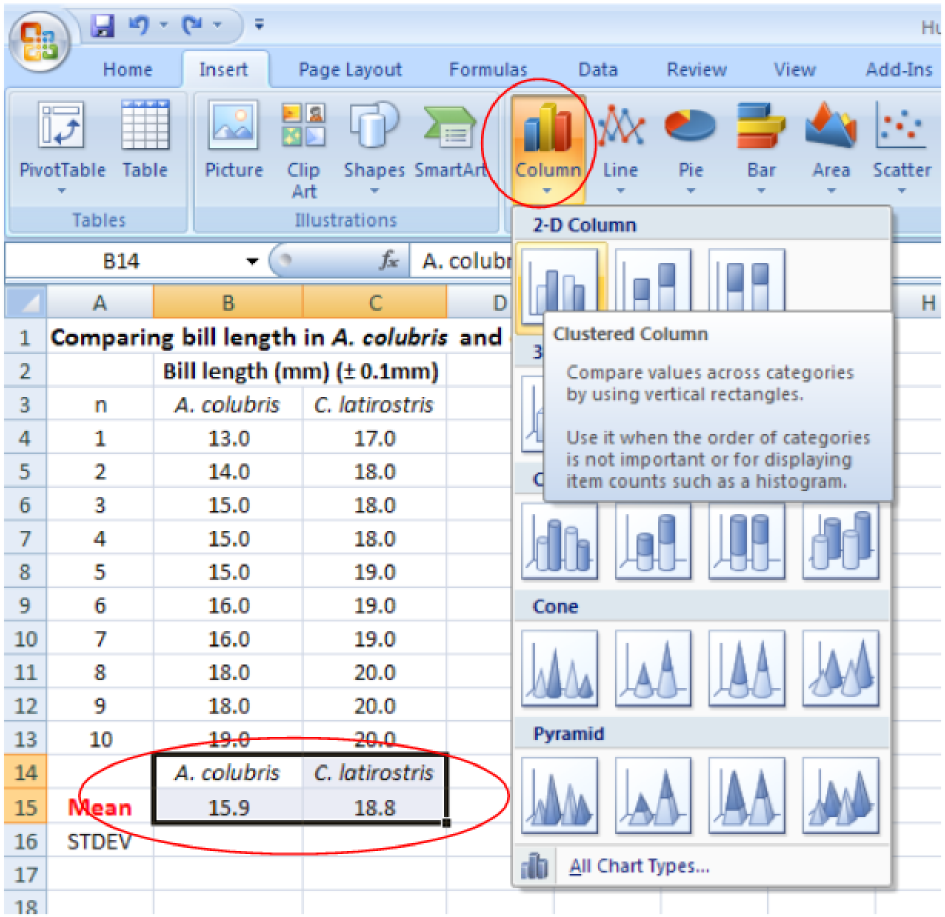
Then highlight the data to be processed

To calculate it yourself:

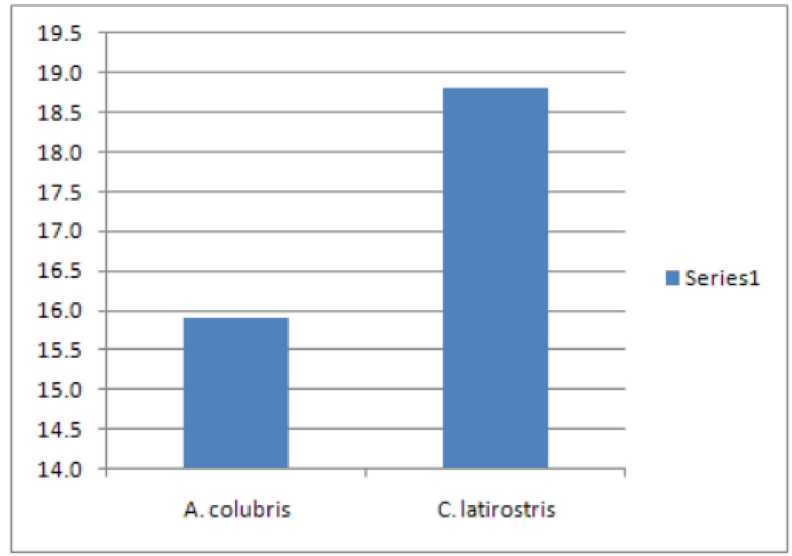
$$\text{mean } (\bar{x}) = \frac{\sum x}{n} \quad \left(\frac{\text{sum of values}}{\text{sample size}}\right)$$


Hummingbirds.xlsx - Microsoft Excel
Home
Insert
Page Layout
Formulas
Data
Review
View
Add-Ins
Nitro PDF
Insert Function
AutoSum
Recently Used
Financial
Logical
Text
Date & Time
Lookup & Reference
Math & Trig
More Functions
Function Library
Name Manager
Define Name
Use in Formula
Create from Selection
Defined Names
Trace Precedents
Trace Dependents
Remove Arrows
Formula Audi
AVERAGE
=AVERAGE(B4:B13)
Comparing bill length in A. colubris and C. latirostris
Bill length (mm) (± 0.1mm)
n
A. colubris
C. latirostris
1 15.0 18.0
2 16.0 19.0
3 13.0 20.0
4 18.0 20.0
5 19.0 20.0
6 14.0 19.0
7 16.0 18.0
8 15.0 17.0
9 15.0 18.0
10 18.0 19.0
Mean
GE(B4:B13)
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:

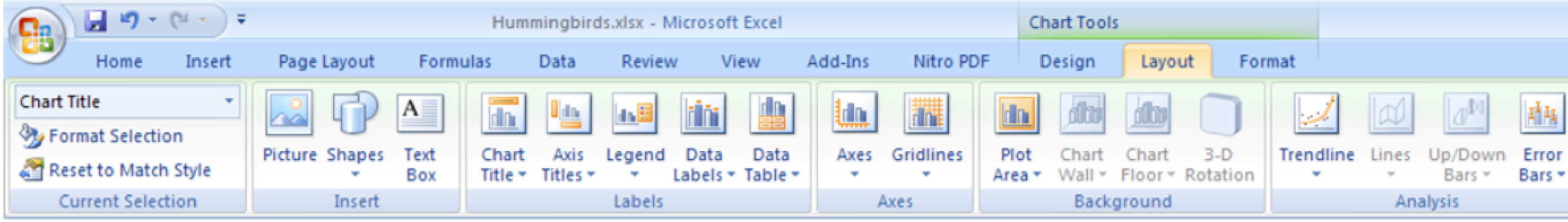


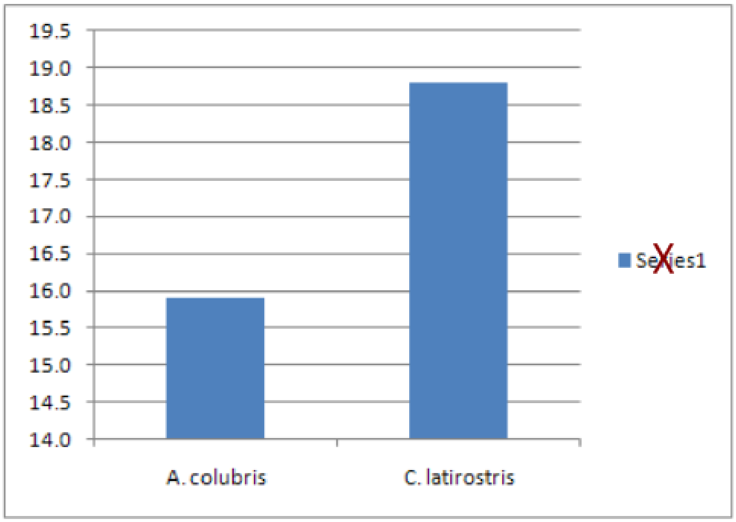
Go for the simplest style



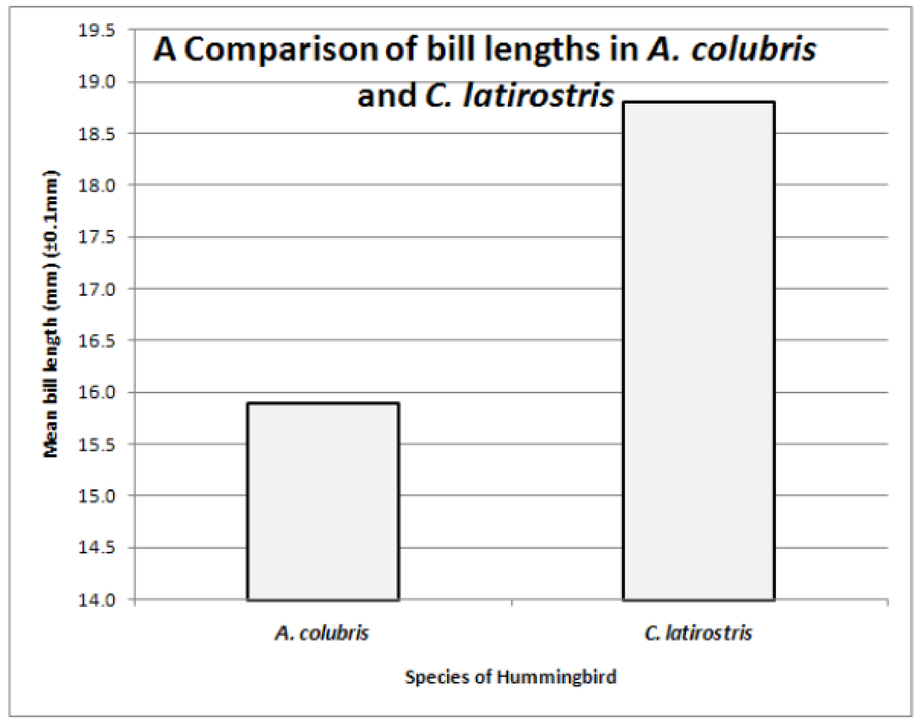
And then edit it.

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



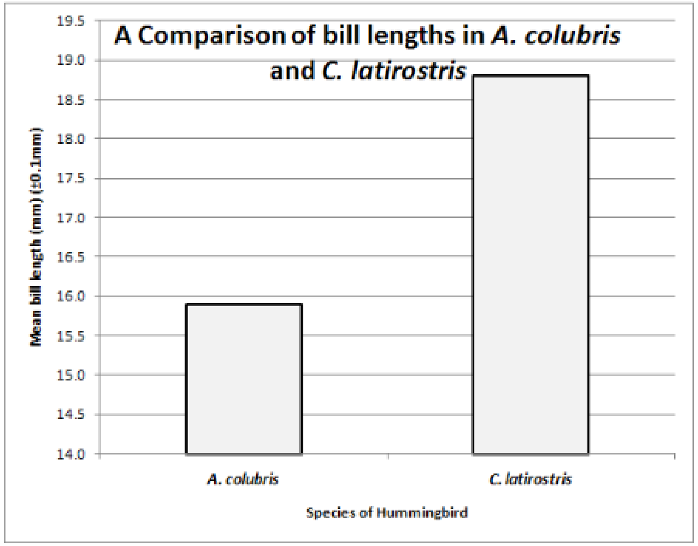


Edit using 'layout' options to meet acceptable standards.



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.

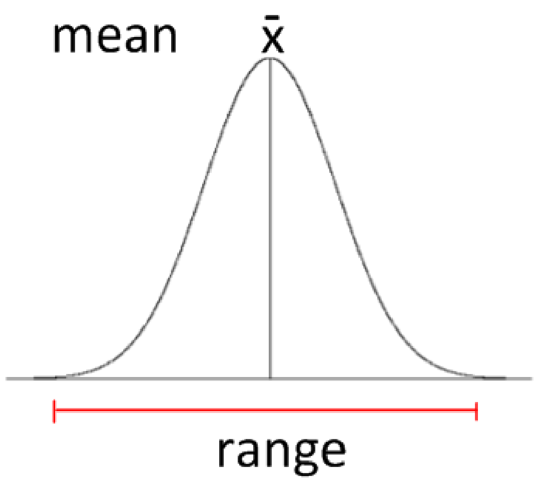
C. latirostris has a higher mean bill length than *A. colubris*...



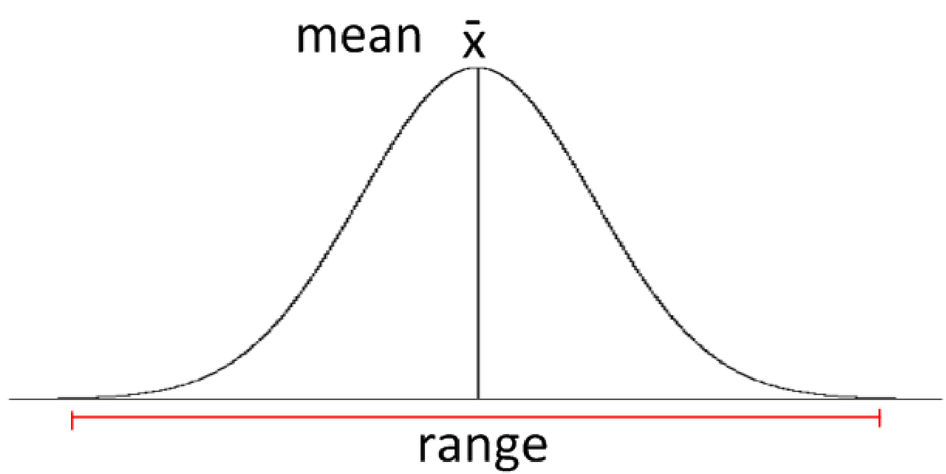
... but that is only part of the story.

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,

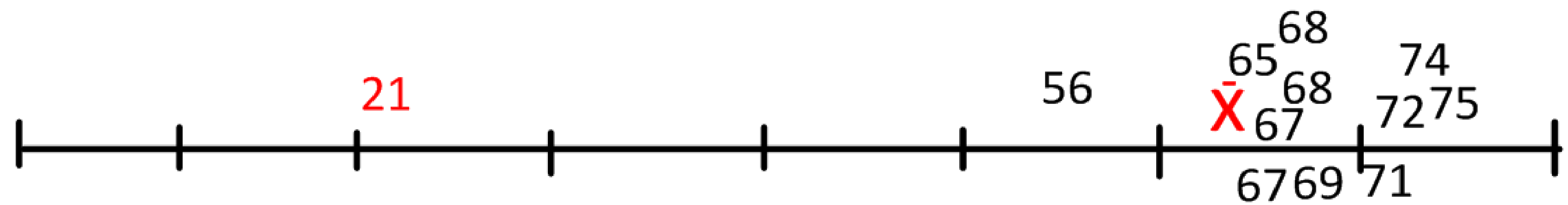
max-min values = 75 - 21 = 54

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

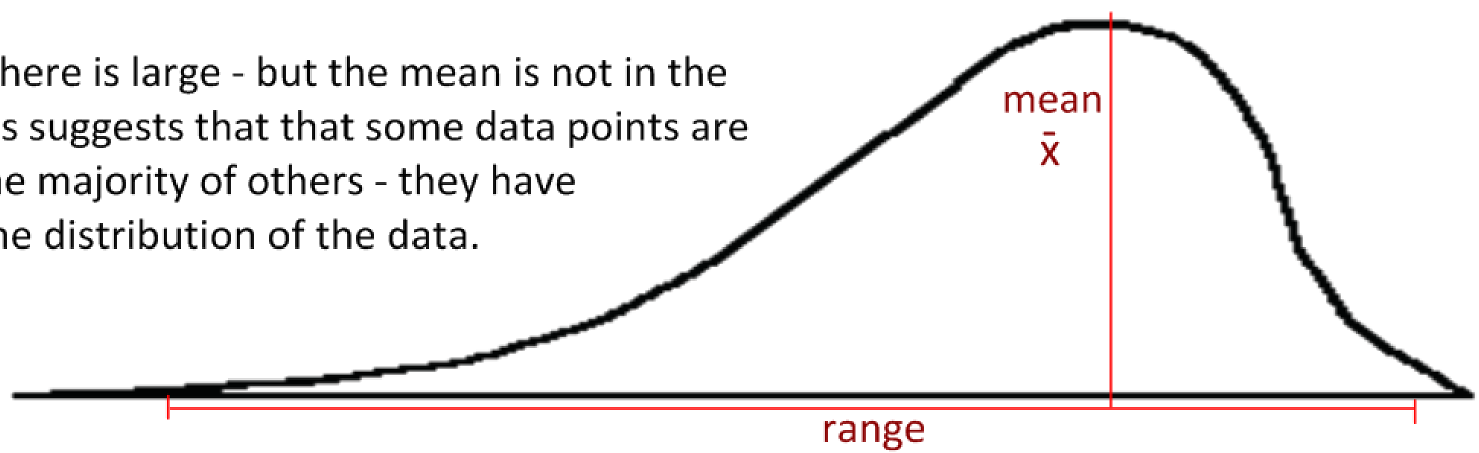
This suggests a large variability, but look more closely:



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.

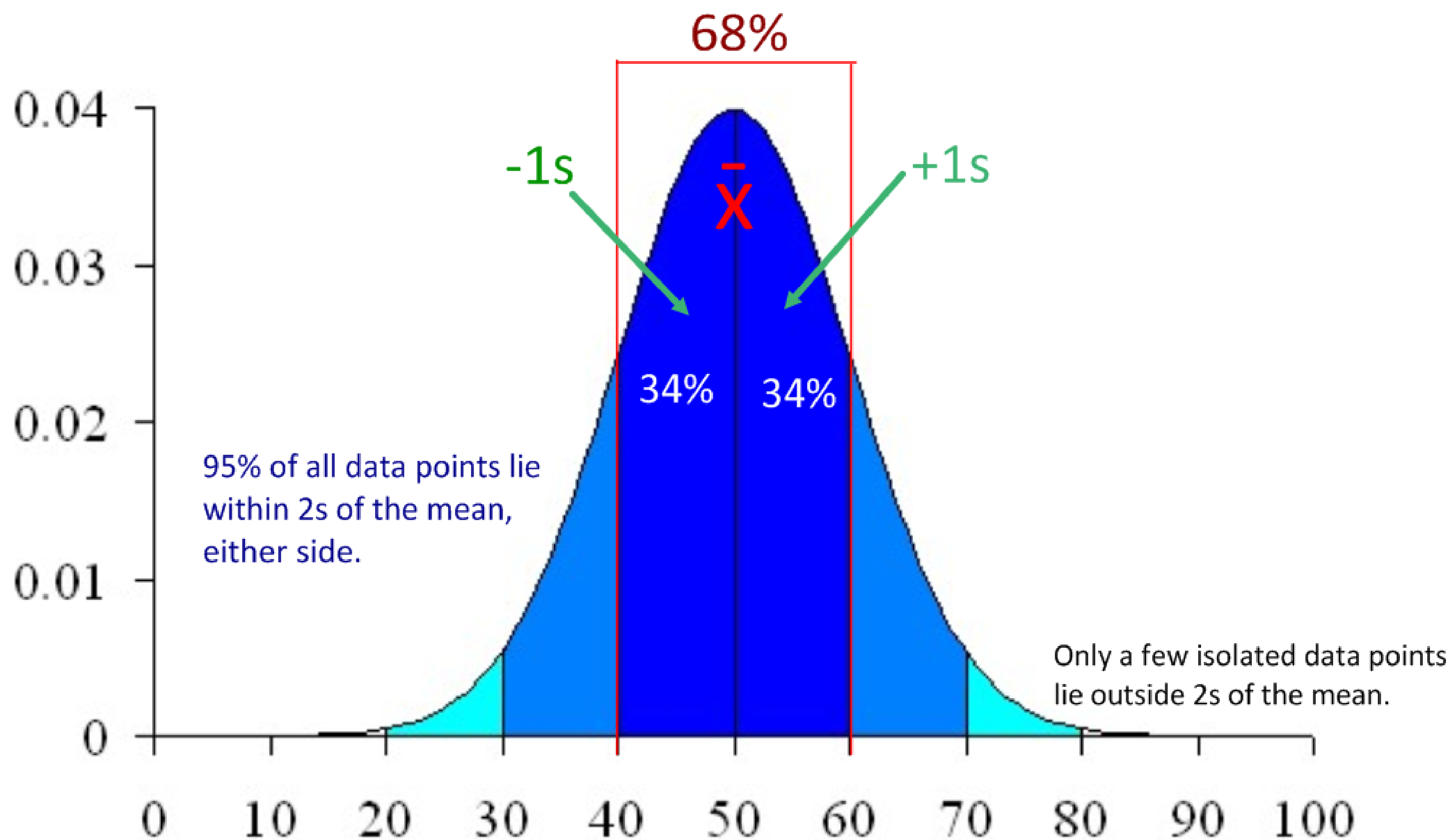
The range here is large - but the mean is not in the centre. This suggests that that some data points are far from the majority of others - they have SKEWED the distribution of the data.



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

68% of all data fall within ± 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

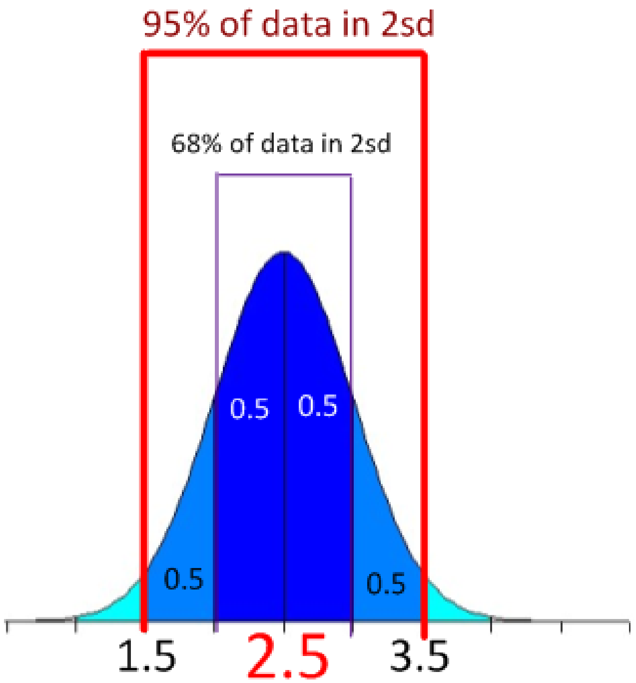
A set of length measurements are taken with a mean of 2.5cm and a standard deviation of 0.5cm. Which of the following statements is true?

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 ±1sd
So 68% are between 2.0cm and 3.0cm

95% of a data are within ±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 ±1

Standard deviation is a measure of
where most of data (68% ±1sd) 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?

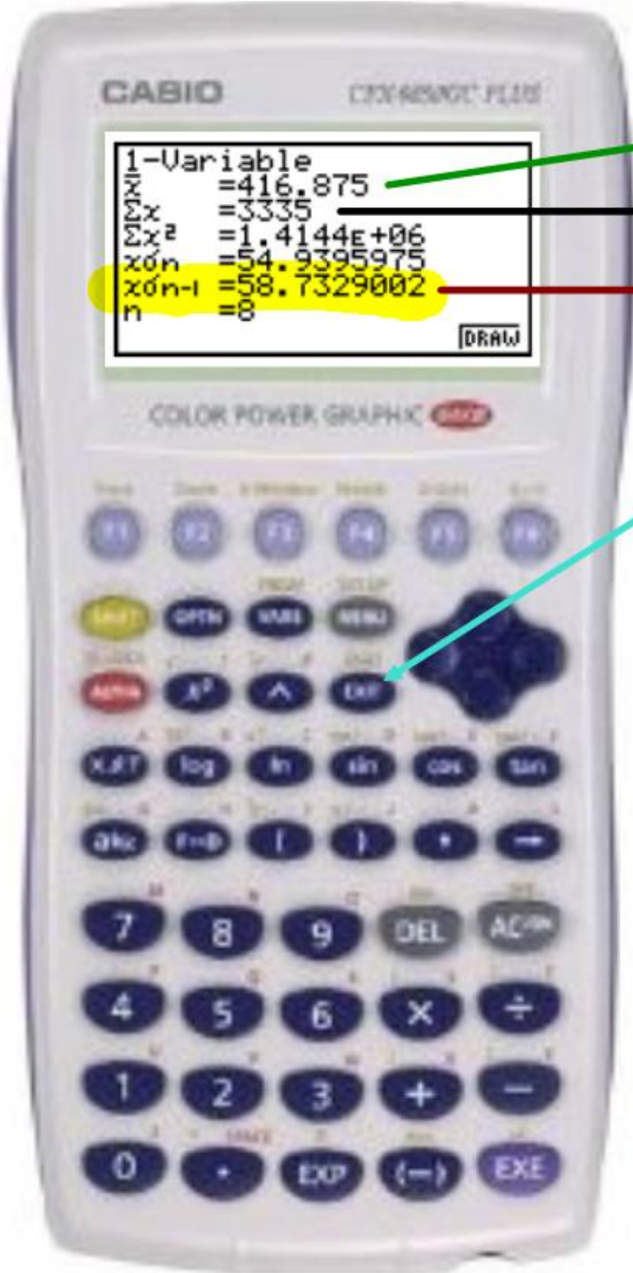
It's always a good idea to read the instructions...

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

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:

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

For Texas Instruments help, visit:

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

Using a Scientific Calculator to find Standard Deviation

1. ON - MODE [3] (STAT - statistics)

2. SHIFT [1]
   then choose 2:Data

3. Delete old data and enter new data
   (enter number, then [=])

4. At the bottom of the data:
   SHIFT [1] (Stat)
   and then hit 5:Var

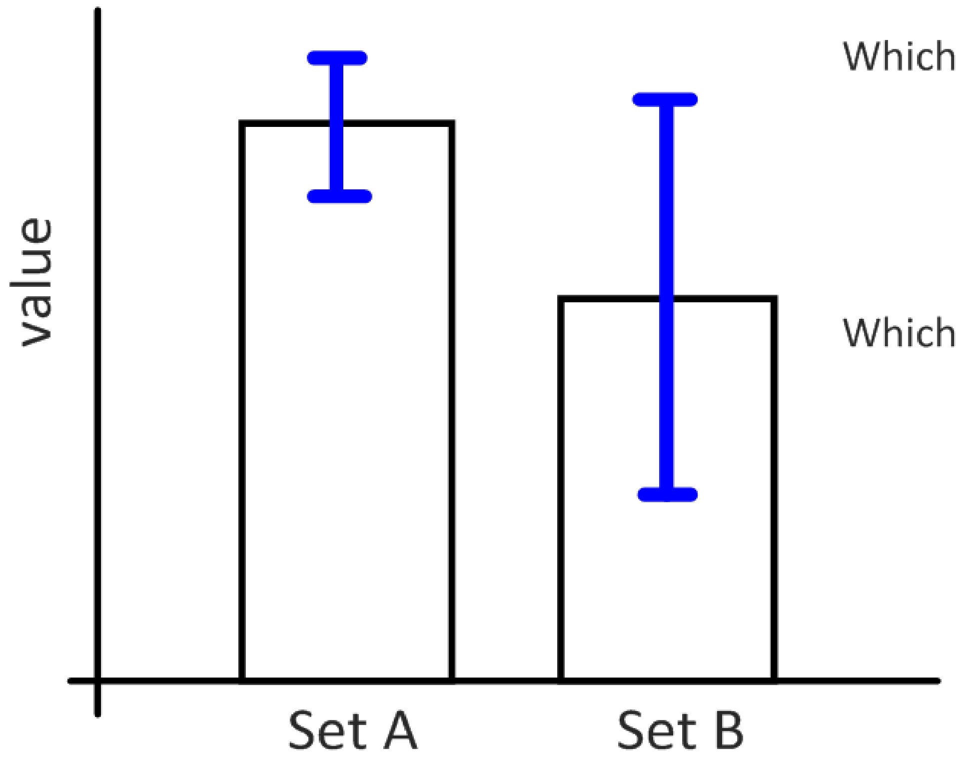
5. Select 4: $x\delta n-1$ ← Standard Deviation

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?

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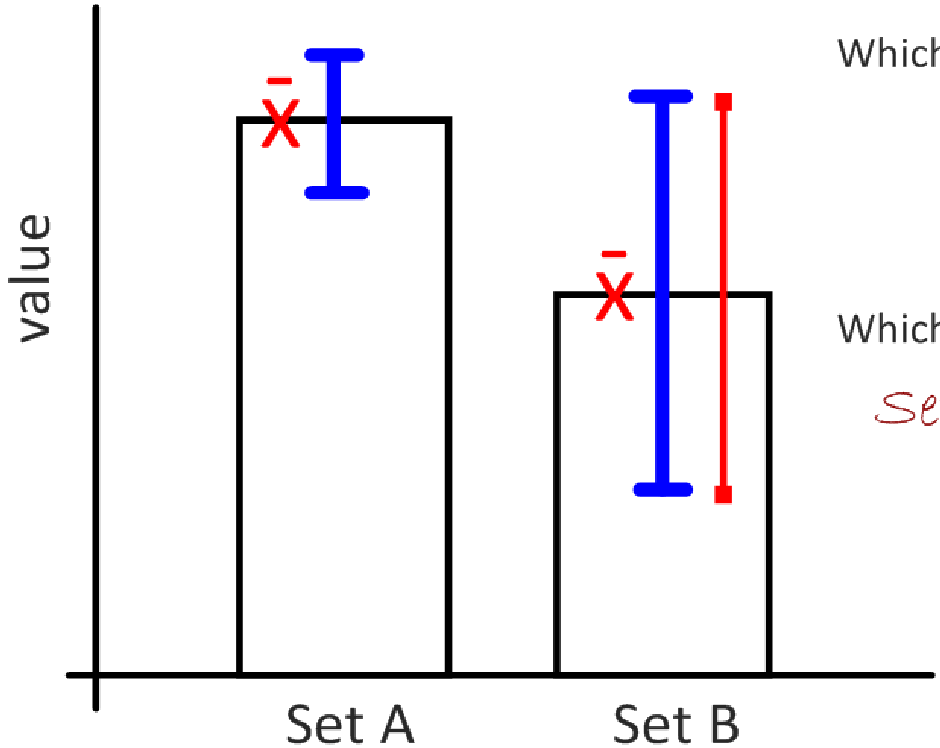


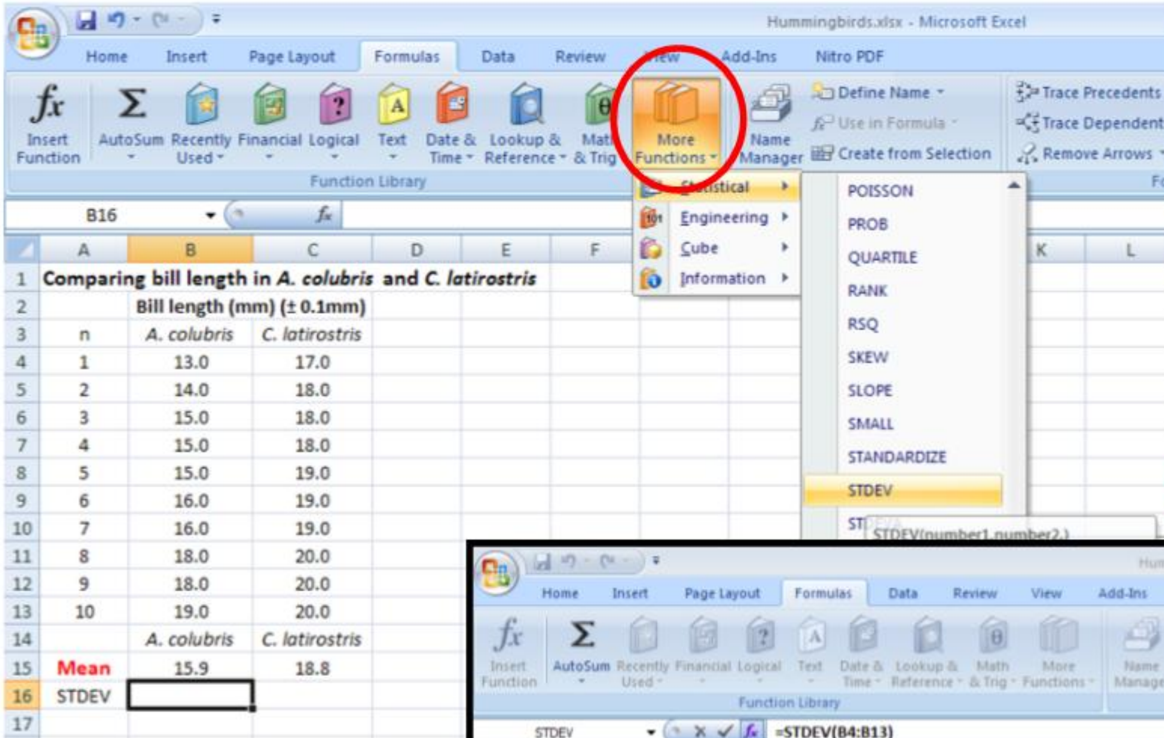
Which of these sets of data has the largest mean?

Set A

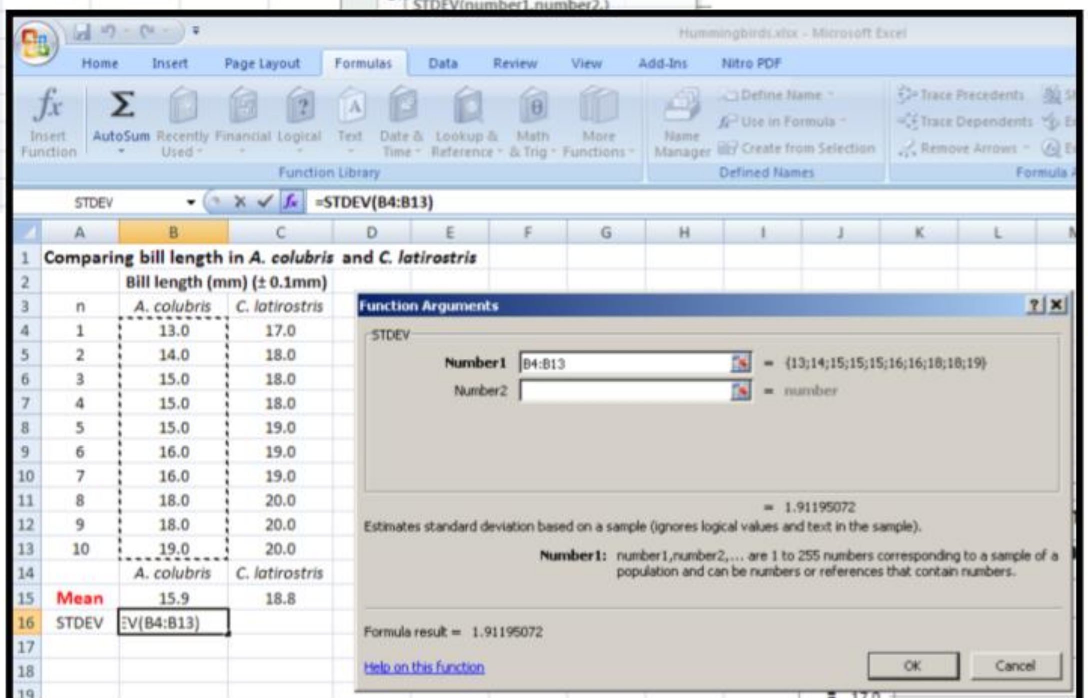
Which set has the greatest variability in the data?

Set B: large standard deviation
= high variability

Using Excel to calculate Standard Deviation:

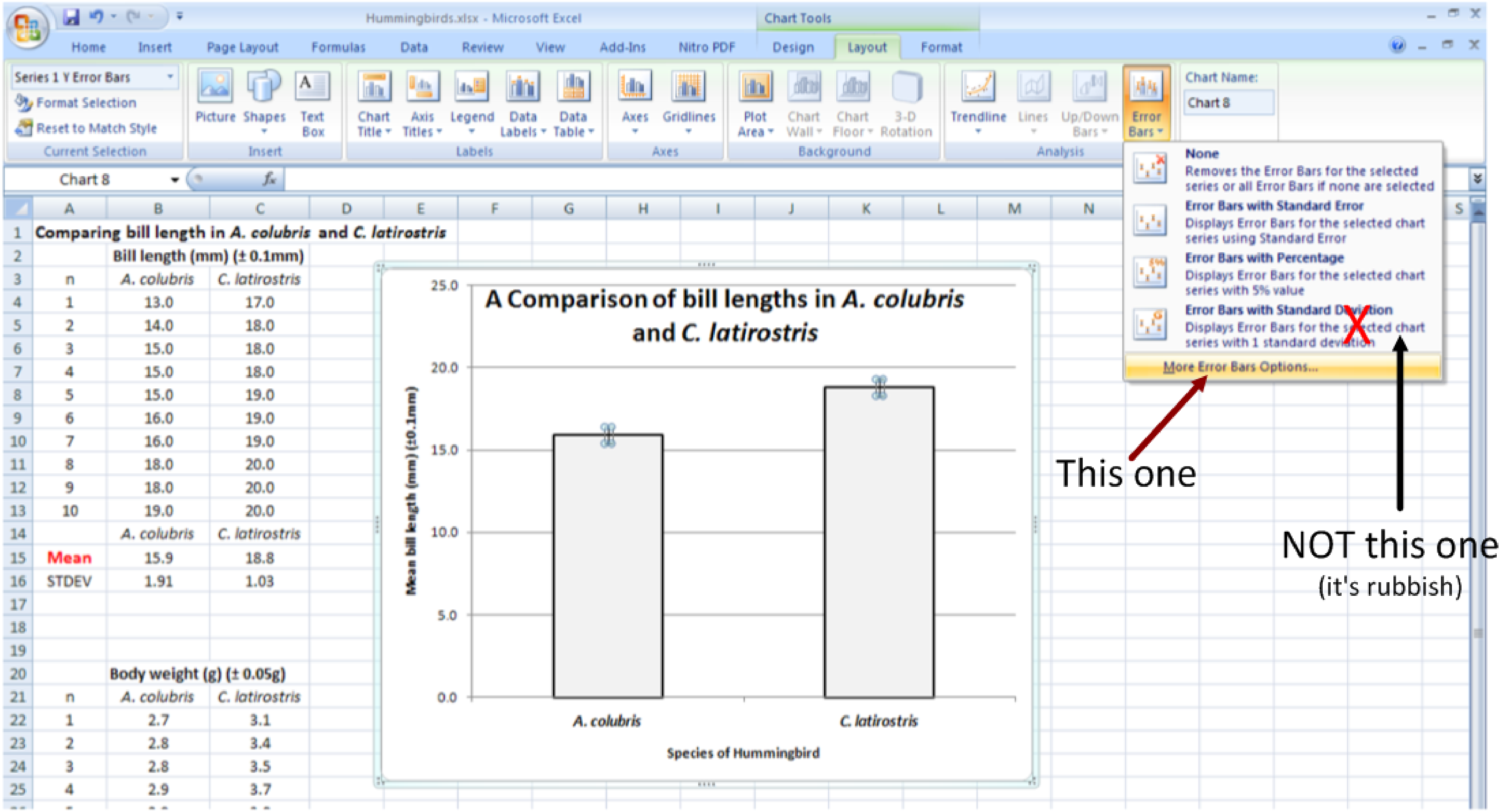


STDEV (not STDEVA)



Highlight raw data only

Plot standard deviation as error bars on the graph:



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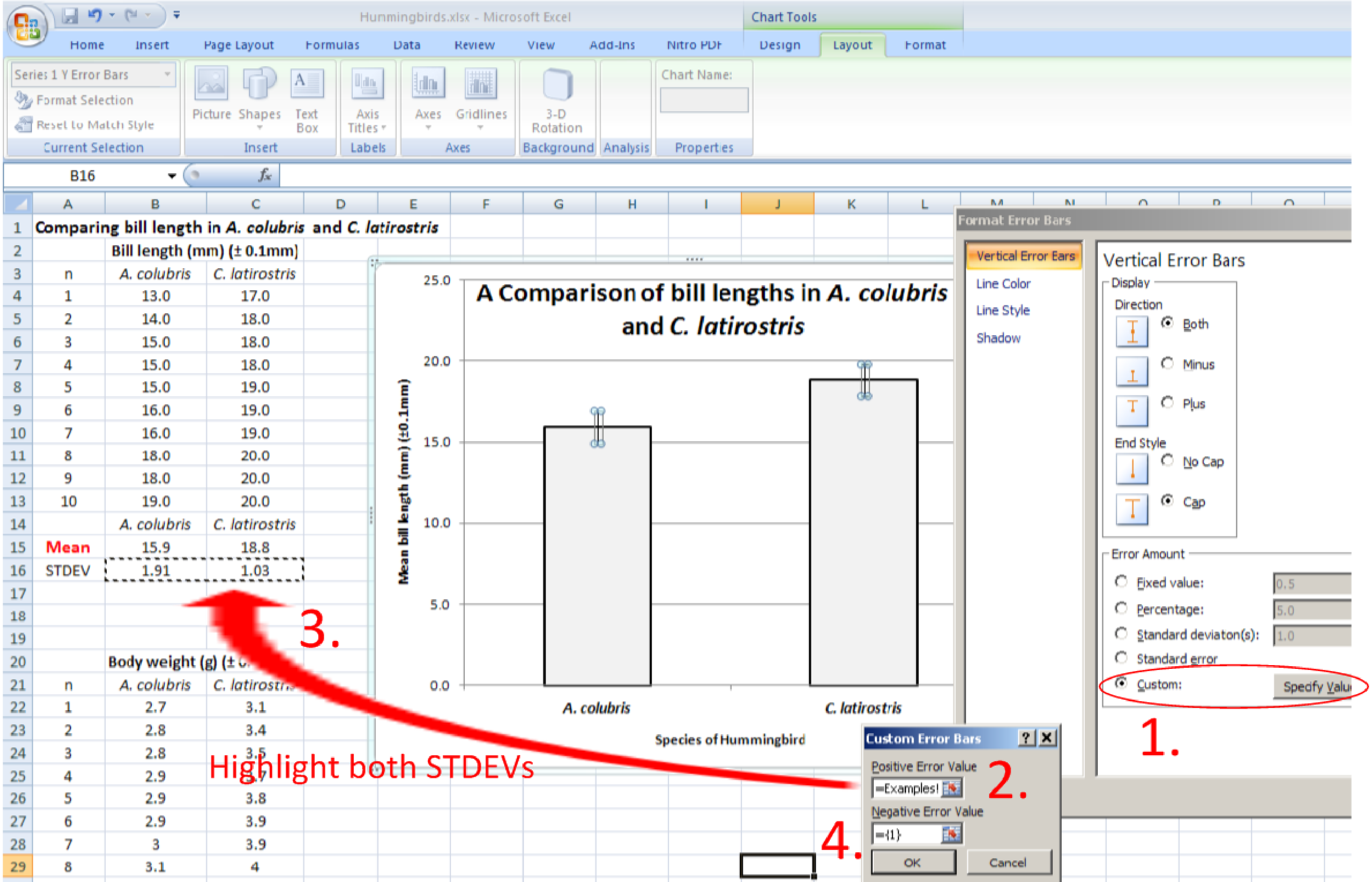

Do it again to create the negative error bar

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

	A	B	C
1	**Comparing bill length in *A. colubris* and *C. latirostris***		
2		**Bill length (mm) (± 0.1mm)**	
3	n	*A. colubris*	*C. latirostris*
4	1	13.0	17.0
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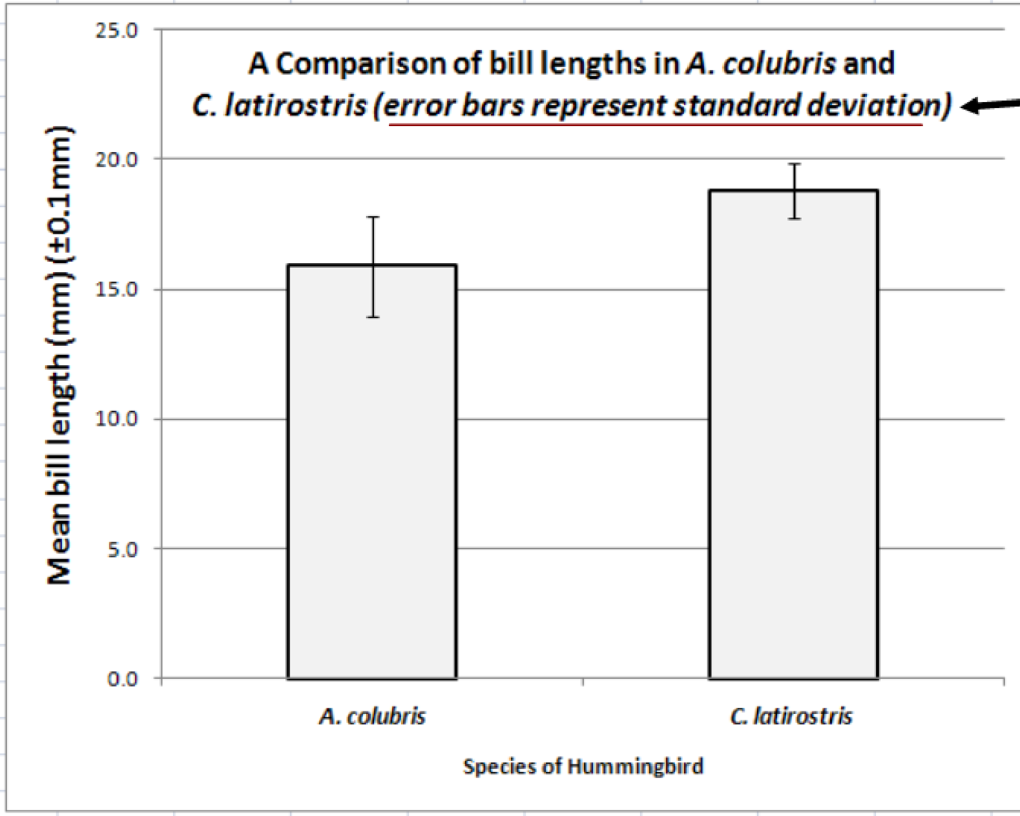
9	6	16.0	19.0
10	7	16.0	19.0
11	8	18.0	20.0
12	9	18.0	20.0
13	10	19.0	20.0
14		*A. colubris*	*C. latirostris*
15	Mean	15.9	18.8
16	STDEV	1.91	1.03

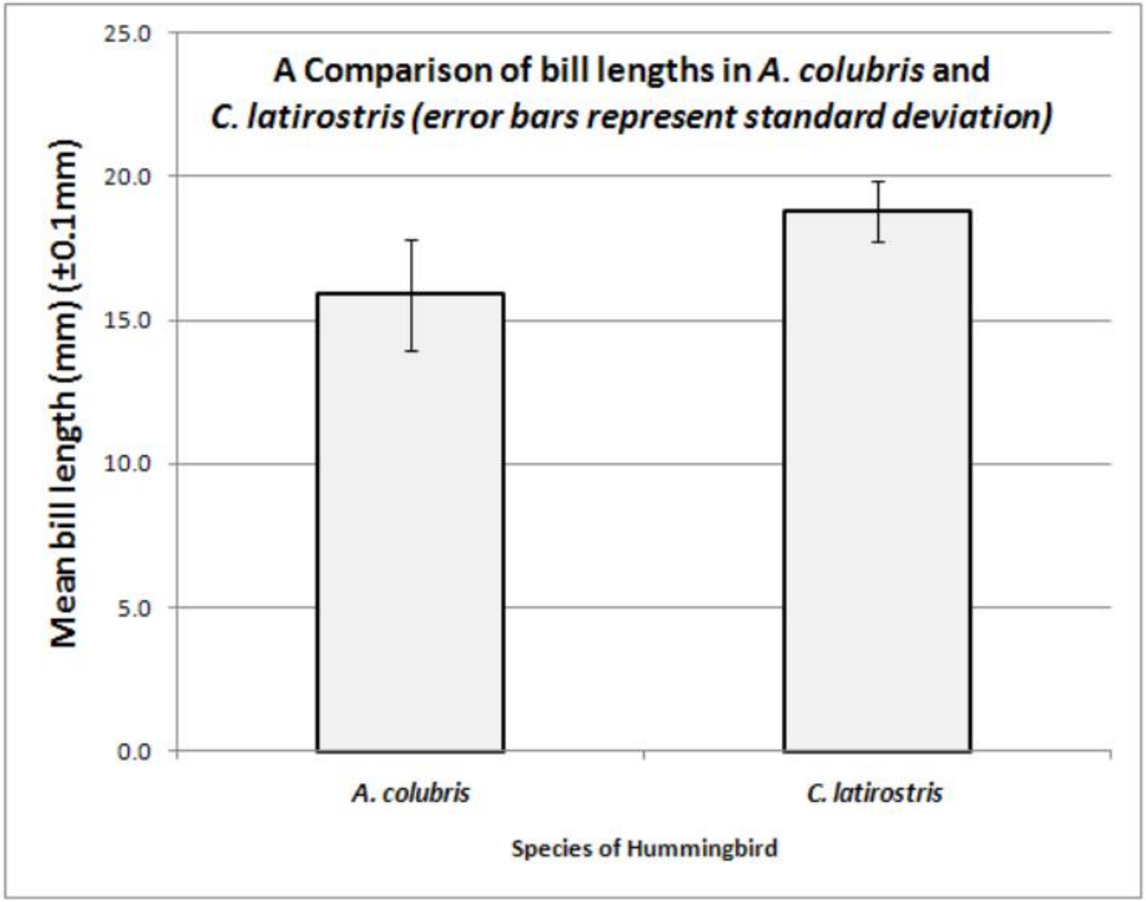


adjust title

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.

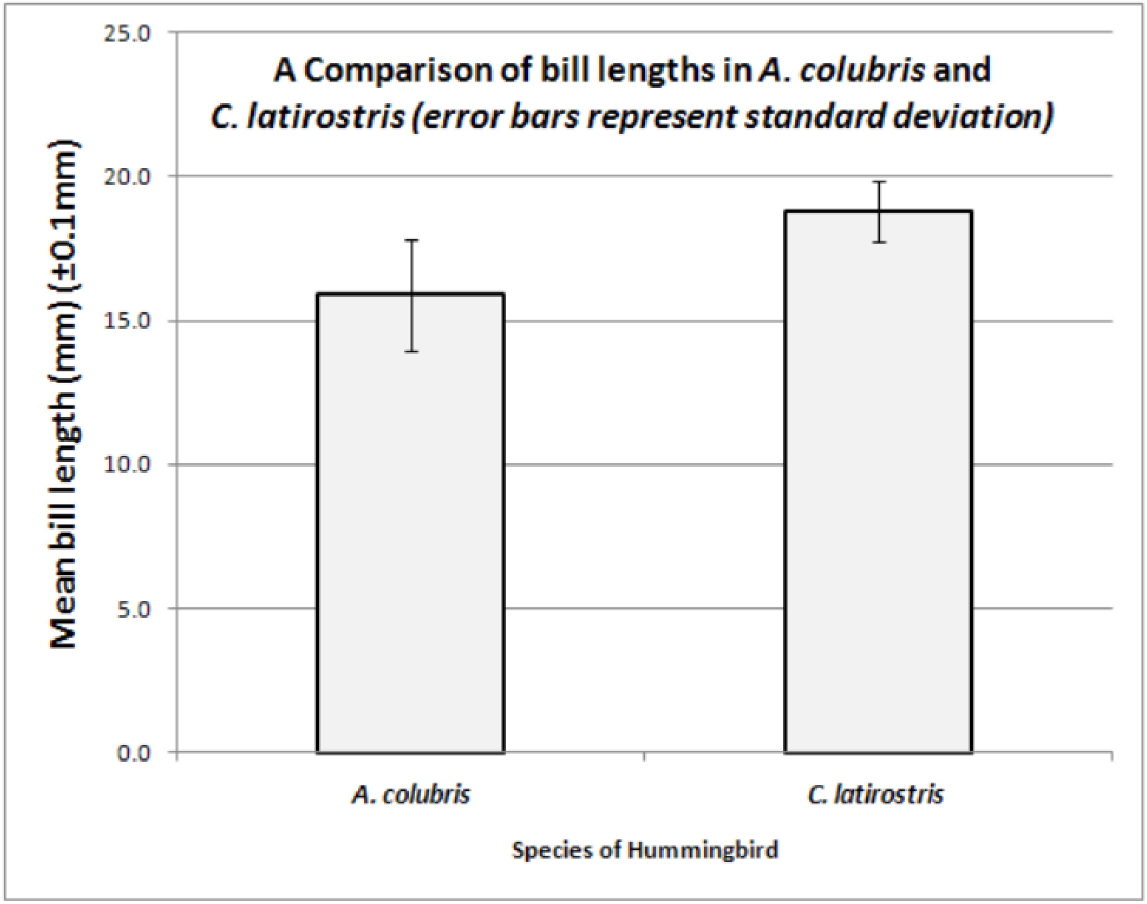
Which sample population has:



A. The longest mean bill?

B. The greatest variability in data?

Which sample population has:



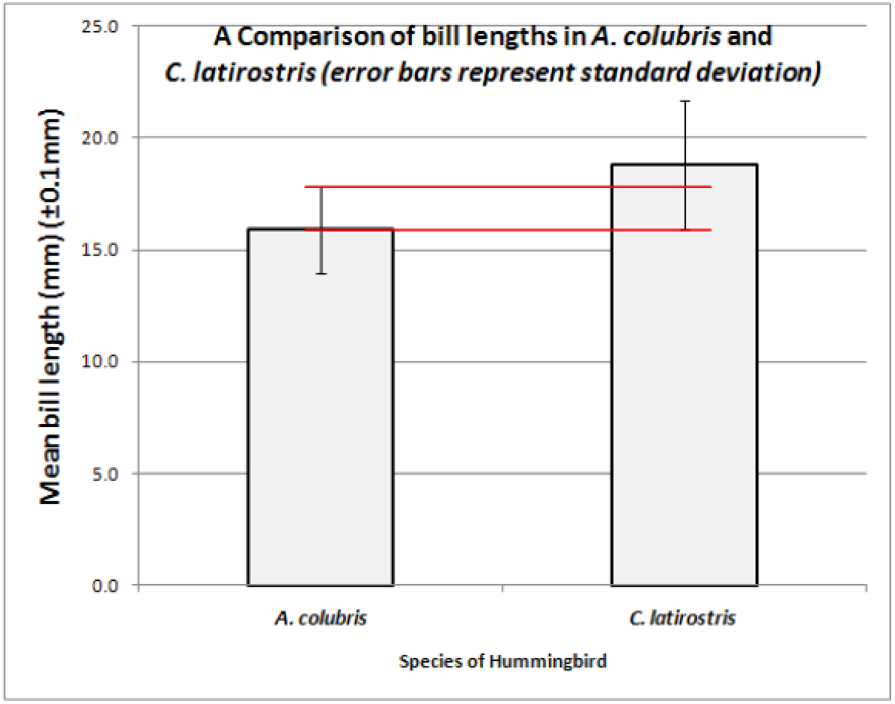
A. The longest mean bill?

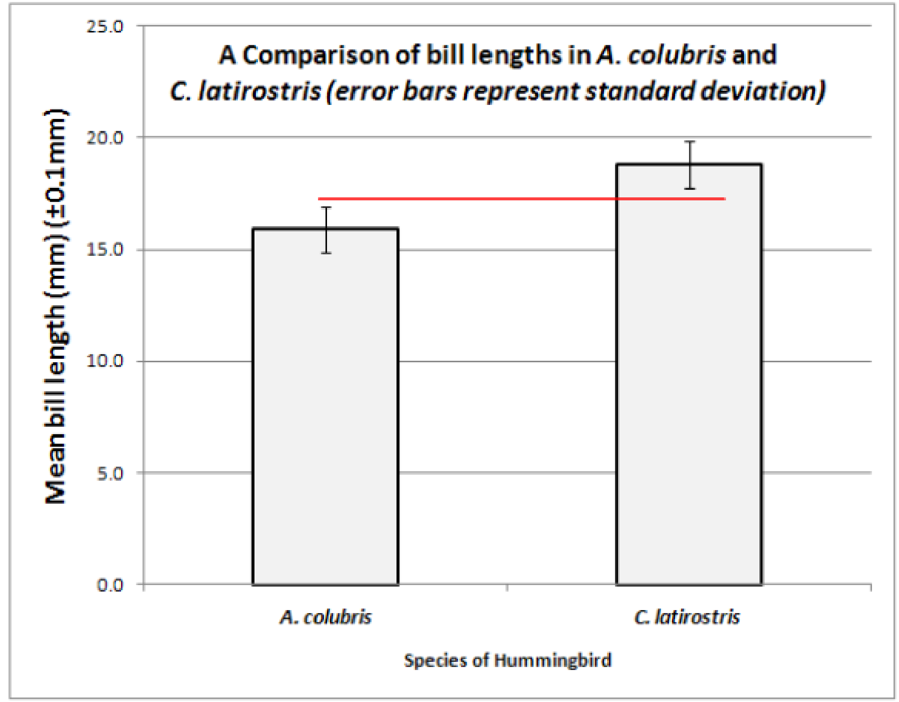
C. latirostris

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 ∴ lots of shared data

No overlap ∴ no (or very little) shared data

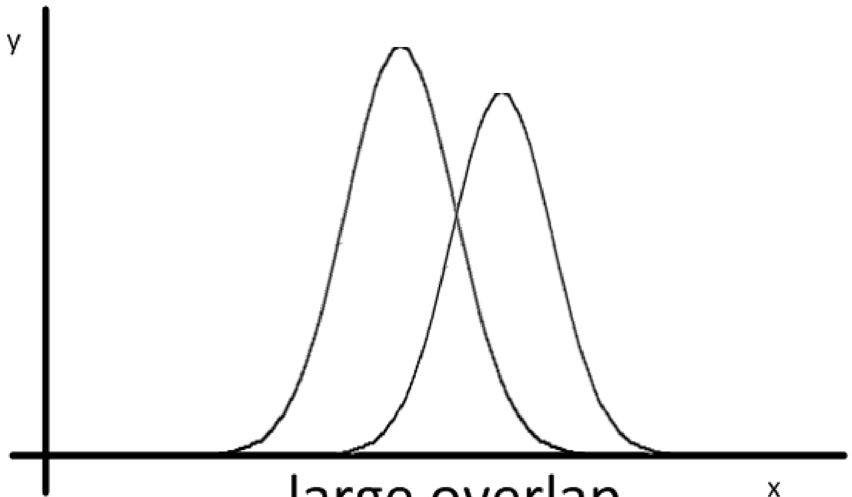
Results are not likely to be significantly different

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

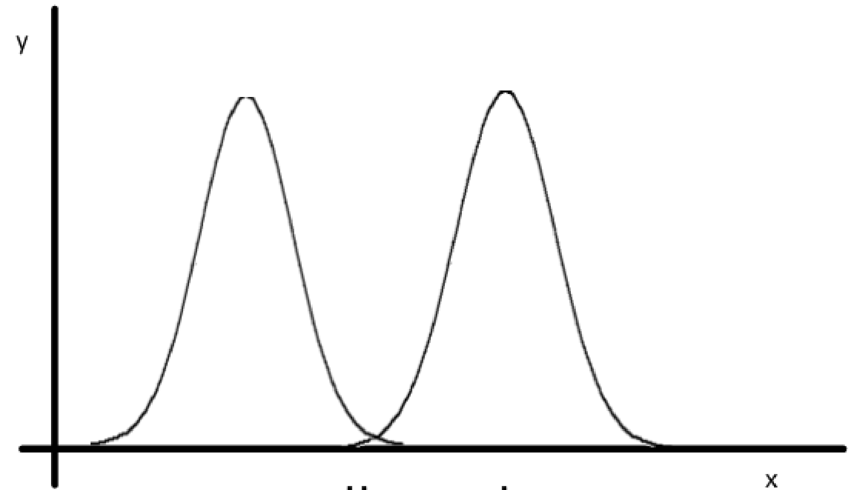
Results are likely to be significantly different

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

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



large overlap



small overlap

Large overlap ∴ lots of shared data

Results are not likely to be significantly different

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

Small overlap ∴ 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...

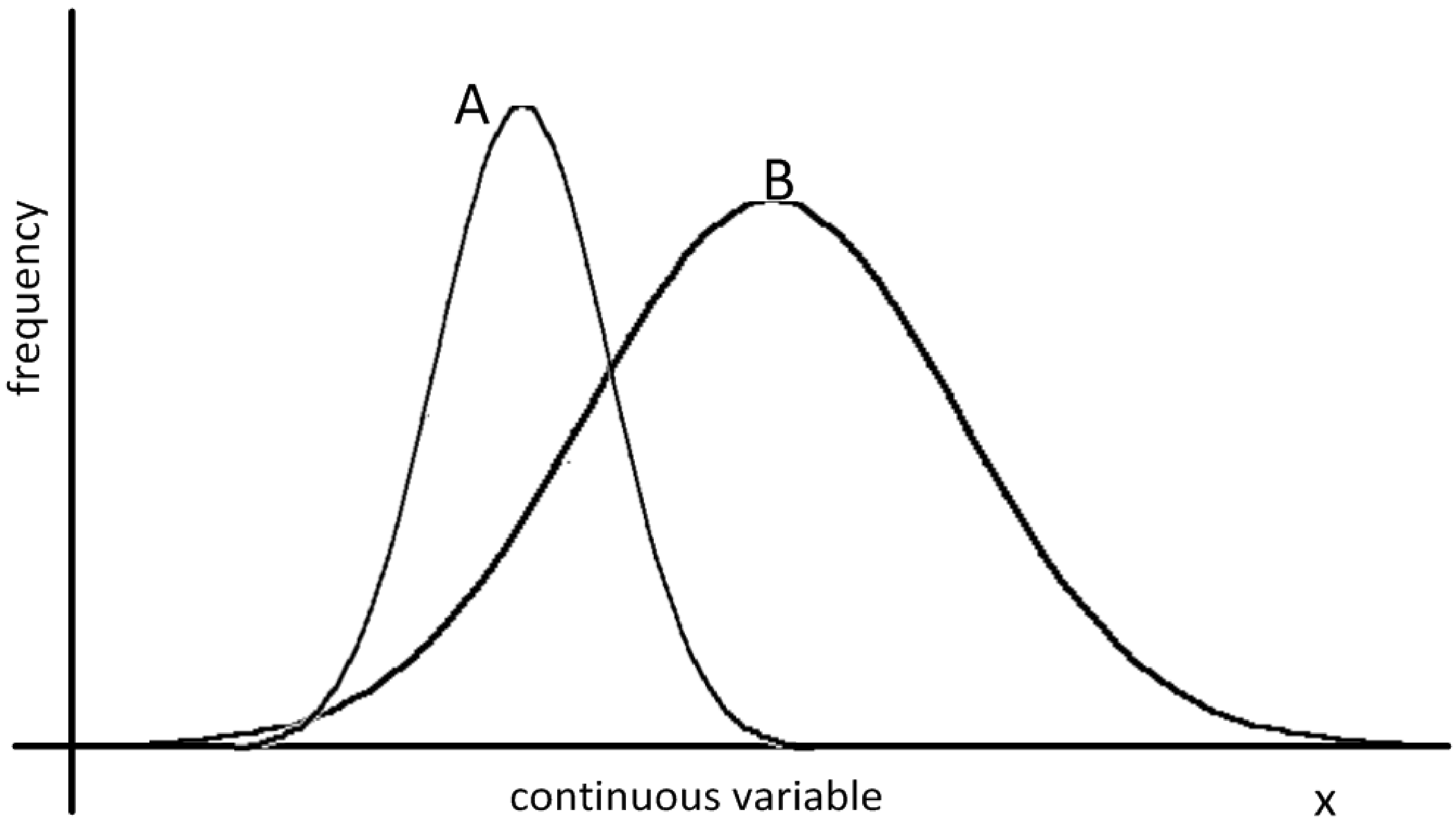
a. a larger range (high variability)?

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...

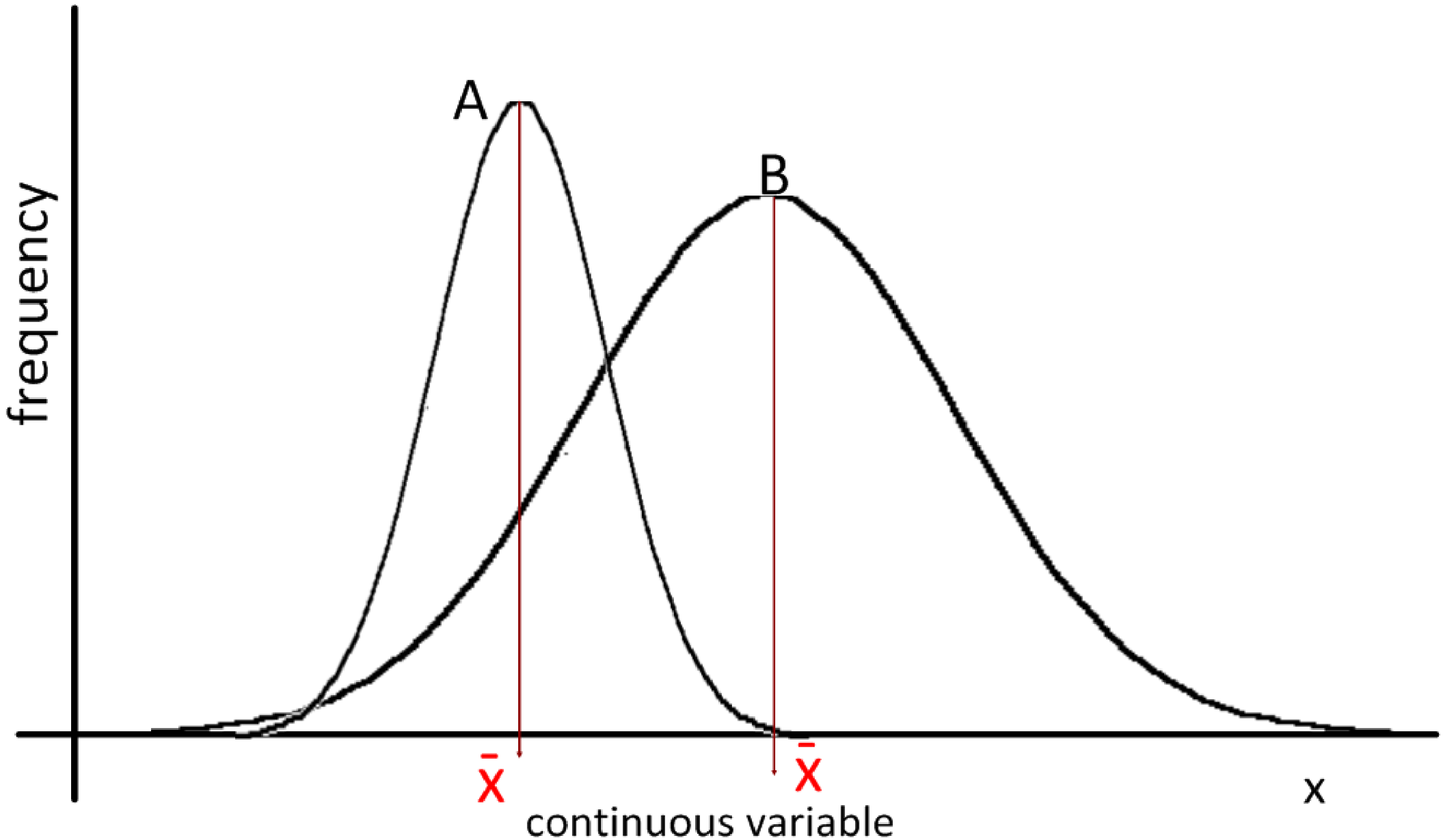
a. a larger range (high variability)? Set B

b. a greater standard deviation? Set B

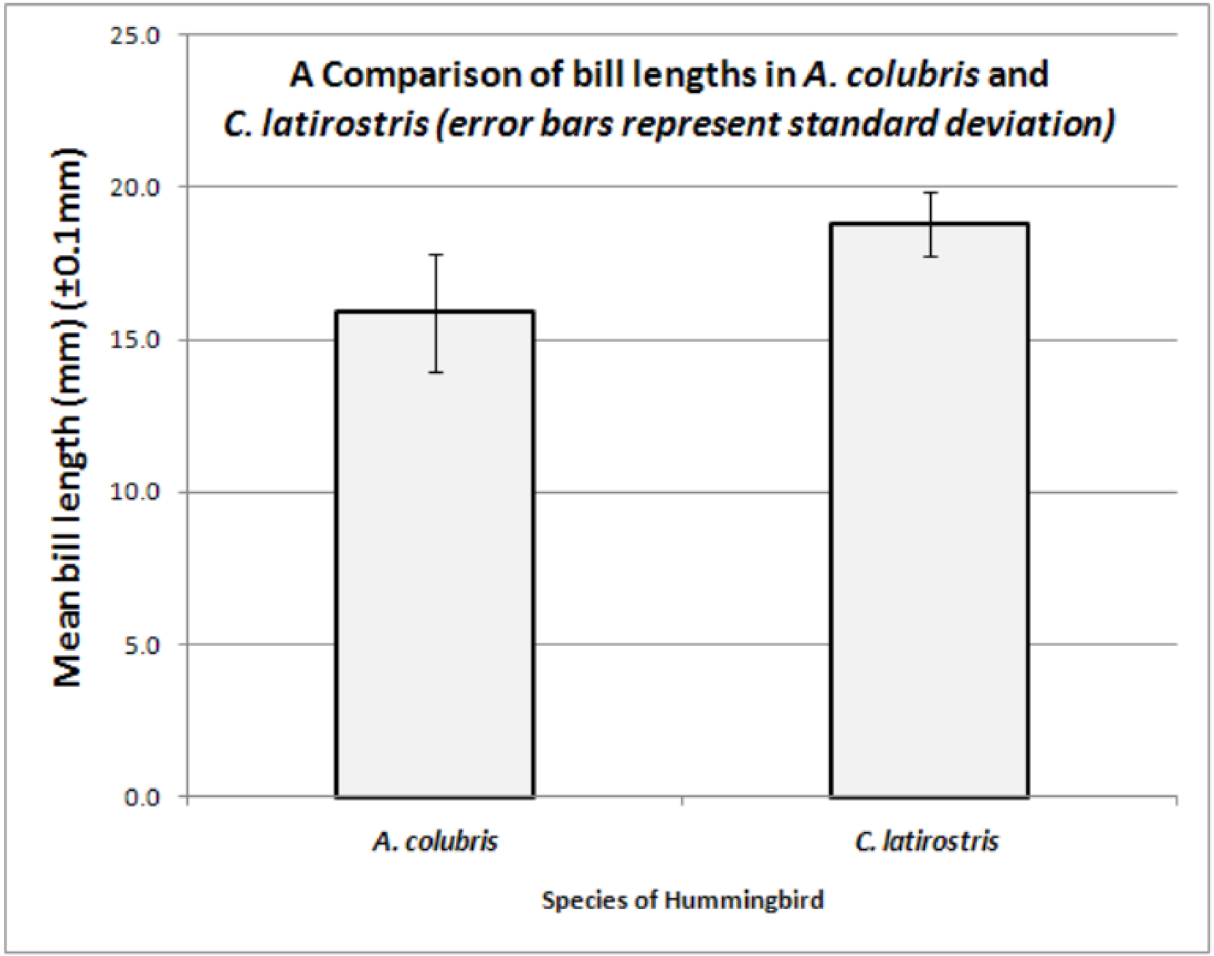
c. more precise results? Set A (can be suggested)

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.

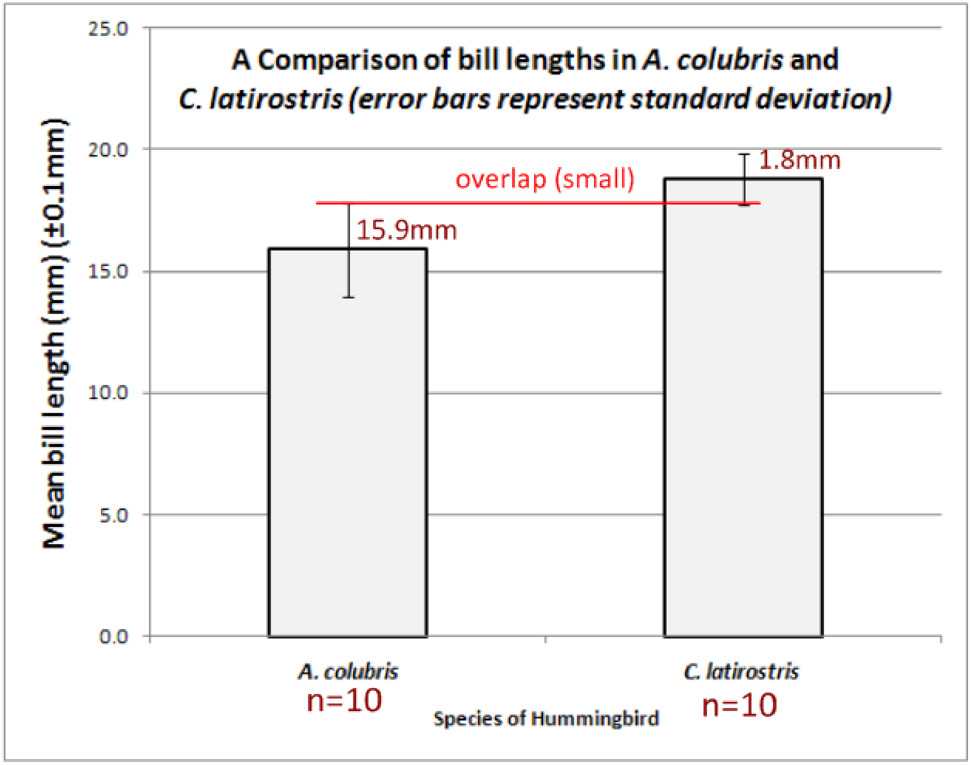


Is the difference between these means real or the result of chance?

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*.

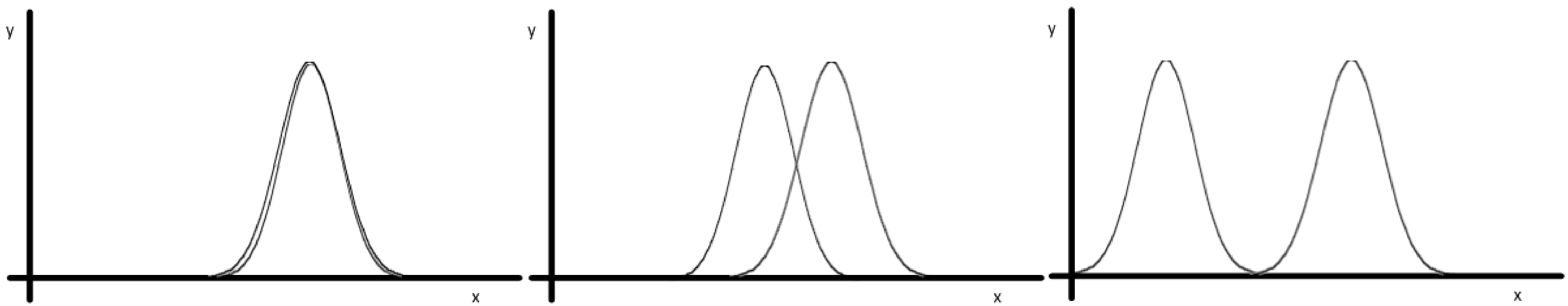
We can also see some overlap in the data, as shown by the error bars.

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:



P=1 (the data are identical) P=0.5 (half are in common) P=0 (no shared data)

The smaller the overlap, the more significant our results.

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

H_o = "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 (α) (confidence = 1-α)				
P	0.10	0.05	0.025	0.01	0.005
	less confident				more confident
α	90%	95%	97.5%	99%	99.5%

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degrees of freedom
(total sample size -2)

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P	0.10	0.05	0.025	0.01	0.005
	less confident				more confident
α	90%	95%	97.5%	99%	99.5%
df					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

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(total sample size -2)

	Significance (α) (confidence = 1-α)				
P	0.10	0.05	0.025	0.01	0.005
	less confident				more confident
df / α	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_o = "There is no significant difference"

df =

P =

∴ critical value =

Significance (α) (confidence = 1-α

df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.6
2	1.886	2.920	4.303	6.965	9.9
3	1.638	2.353	3.182	4.541	5.8
4	1.533	2.132	2.776	3.747	4.6
5	1.476	2.015	2.571	3.365	4.0
6	1.440	1.943	2.447	3.143	3.7
7	1.415	1.895	2.365	2.998	3.4
8	1.397	1.860	2.306	2.896	3.3
9	1.383	1.833	2.262	2.821	3.2
10	1.372	1.812	2.228	2.764	3.1
11	1.363	1.796	2.201	2.718	3.1
12	1.356	1.782	2.179	2.681	3.0
13	1.350	1.771	2.160	2.650	3.0
14	1.345	1.761	2.145	2.624	2.9
15	1.341	1.753	2.131	2.602	2.9
16	1.337	1.746	2.120	2.583	2.9
17	1.333	1.740	2.110	2.567	2.8
18	1.330	1.734	2.101	2.552	2.8
19	1.328	1.729	2.093	2.539	2.8
20	1.325	1.725	2.086	2.528	2.8
21	1.323	1.721	2.080	2.518	2.8
22	1.321	1.717	2.074	2.508	2.8
23	1.319	1.714	2.069	2.500	2.8
24	1.318	1.711	2.064	2.492	2.7
25	1.316	1.708	2.060	2.485	2.7
26	1.315	1.706	2.056	2.479	2.7
27	1.314	1.703	2.052	2.473	2.7
28	1.313	1.701	2.048	2.467	2.7
29	1.311	1.699	2.045	2.462	2.7
30	1.310	1.697	2.042	2.457	2.7

Worked example:

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

H_o = "There is no significant difference"

df = (12+13)-2 = 23

P =

∴ critical value =

	Significance (α) (confidence = 1-α				
df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.
2	1.886	2.920	4.303	6.965	9.
3	1.638	2.353	3.182	4.541	5.
4	1.533	2.132	2.776	3.747	4.
5	1.476	2.015	2.571	3.365	4.
6	1.440	1.943	2.447	3.143	3.
7	1.415	1.895	2.365	2.998	3.
8	1.397	1.860	2.306	2.896	3.
9	1.383	1.833	2.262	2.821	3.
10	1.372	1.812	2.228	2.764	3.
11	1.363	1.796	2.201	2.718	3.
12	1.356	1.782	2.179	2.681	3.
13	1.350	1.771	2.160	2.650	3.
14	1.345	1.761	2.145	2.624	2.
15	1.341	1.753	2.131	2.602	2.
16	1.337	1.746	2.120	2.583	2.
17	1.333	1.740	2.110	2.567	2.
18	1.330	1.734	2.101	2.552	2.
19	1.328	1.729	2.093	2.539	2.
20	1.325	1.725	2.086	2.528	2.
21	1.323	1.721	2.080	2.518	2.
22	1.321	1.717	2.074	2.508	2.
23	1.319	1.714	2.069	2.500	2.
24	1.318	1.711	2.064	2.492	2.
25	1.316	1.708	2.060	2.485	2.
26	1.315	1.706	2.056	2.479	2.
27	1.314	1.703	2.052	2.473	2.
28	1.313	1.701	2.048	2.467	2.
29	1.311	1.699	2.045	2.462	2.
30	1.310	1.697	2.042	2.457	2.

Worked example:

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

H_o = "There is no significant difference"

df = (12+13)-2 = 23

P = 0.05

∴ critical value =

	Significance (α) (confidence = 1-α				
df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.
2	1.886	2.920	4.303	6.965	9.
3	1.638	2.353	3.182	4.541	5.
4	1.533	2.132	2.776	3.747	4.
5	1.476	2.015	2.571	3.365	4.
6	1.440	1.943	2.447	3.143	3.
7	1.415	1.895	2.365	2.998	3.
8	1.397	1.860	2.306	2.896	3.
9	1.383	1.833	2.262	2.821	3.
10	1.372	1.812	2.228	2.764	3.
11	1.363	1.796	2.201	2.718	3.
12	1.356	1.782	2.179	2.681	3.
13	1.350	1.771	2.160	2.650	3.
14	1.345	1.761	2.145	2.624	2.
15	1.341	1.753	2.131	2.602	2.
16	1.337	1.746	2.120	2.583	2.
17	1.333	1.740	2.110	2.567	2.
18	1.330	1.734	2.101	2.552	2.
19	1.328	1.729	2.093	2.539	2.
20	1.325	1.725	2.086	2.528	2.
21	1.323	1.721	2.080	2.518	2.
22	1.321	1.717	2.074	2.508	2.
23	1.319	1.714	2.069	2.500	2.
24	1.318	1.711	2.064	2.492	2.
25	1.316	1.708	2.060	2.485	2.
26	1.315	1.706	2.056	2.479	2.
27	1.314	1.703	2.052	2.473	2.
28	1.313	1.701	2.048	2.467	2.
29	1.311	1.699	2.045	2.462	2.
30	1.310	1.697	2.042	2.457	2.

Worked example:

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

H_o = "There is no significant difference"

df = (12+13)-2 = 23

P = 0.05

∴ critical value = 1.714

Significance (α) (confidence = 1-α

df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.
2	1.886	2.920	4.303	6.965	9.
3	1.638	2.353	3.182	4.541	5.
4	1.533	2.132	2.776	3.747	4.
5	1.476	2.015	2.571	3.365	4.
6	1.440	1.943	2.447	3.143	3.
7	1.415	1.895	2.365	2.998	3.
8	1.397	1.860	2.306	2.896	3.
9	1.383	1.833	2.262	2.821	3.
10	1.372	1.812	2.228	2.764	3.
11	1.363	1.796	2.201	2.718	3.
12	1.356	1.782	2.179	2.681	3.
13	1.350	1.771	2.160	2.650	3.
14	1.345	1.761	2.145	2.624	2.
15	1.341	1.753	2.131	2.602	2.
16	1.337	1.746	2.120	2.583	2.
17	1.333	1.740	2.110	2.567	2.
18	1.330	1.734	2.101	2.552	2.
19	1.328	1.729	2.093	2.539	2.
20	1.325	1.725	2.086	2.528	2.
21	1.323	1.721	2.080	2.518	2.
22	1.321	1.717	2.074	2.508	2.
23	1.319	1.714	2.069	2.500	2.
24	1.318	1.711	2.064	2.492	2.
25	1.316	1.708	2.060	2.485	2.
26	1.315	1.706	2.056	2.479	2.
27	1.314	1.703	2.052	2.473	2.
28	1.313	1.701	2.048	2.467	2.
29	1.311	1.699	2.045	2.462	2.
30	1.310	1.697	2.042	2.457	2.

Worked example:

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

H_o = "There is no significant difference"

df = (12+13)-2 = 23

P = 0.05

∴ 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_o

If t > cv, reject H_o

Significance (α) (confidence = 1-α

df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.
2	1.886	2.920	4.303	6.965	9.
3	1.638	2.353	3.182	4.541	5.
4	1.533	2.132	2.776	3.747	4.
5	1.476	2.015	2.571	3.365	4.
6	1.440	1.943	2.447	3.143	3.
7	1.415	1.895	2.365	2.998	3.
8	1.397	1.860	2.306	2.896	3.
9	1.383	1.833	2.262	2.821	3.
10	1.372	1.812	2.228	2.764	3.
11	1.363	1.796	2.201	2.718	3.
12	1.356	1.782	2.179	2.681	3.
13	1.350	1.771	2.160	2.650	3.
14	1.345	1.761	2.145	2.624	2.
15	1.341	1.753	2.131	2.602	2.
16	1.337	1.746	2.120	2.583	2.
17	1.333	1.740	2.110	2.567	2.
18	1.330	1.734	2.101	2.552	2.
19	1.328	1.729	2.093	2.539	2.
20	1.325	1.725	2.086	2.528	2.
21	1.323	1.721	2.080	2.518	2.
22	1.321	1.717	2.074	2.508	2.
23	1.319	1.714	2.069	2.500	2.
24	1.318	1.711	2.064	2.492	2.
25	1.316	1.708	2.060	2.485	2.
26	1.315	1.706	2.056	2.479	2.
27	1.314	1.703	2.052	2.473	2.
28	1.313	1.701	2.048	2.467	2.
29	1.311	1.699	2.045	2.462	2.
30	1.310	1.697	2.042	2.457	2.

Worked example:

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

H_o = "There is no significant difference"

df = (12+13)-2 = 23

P = 0.05

∴ 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_o

If t > cv, reject H_o

∴ <u>reject</u> H_0

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

Significance (α) (confidence = 1-α

df	0.10	0.05	0.025	0.01	0.0
1	3.078	6.314	12.706	31.821	63.
2	1.886	2.920	4.303	6.965	9.
3	1.638	2.353	3.182	4.541	5.
4	1.533	2.132	2.776	3.747	4.
5	1.476	2.015	2.571	3.365	4.
6	1.440	1.943	2.447	3.143	3.
7	1.415	1.895	2.365	2.998	3.
8	1.397	1.860	2.306	2.896	3.
9	1.383	1.833	2.262	2.821	3.
10	1.372	1.812	2.228	2.764	3.
11	1.363	1.796	2.201	2.718	3.
12	1.356	1.782	2.179	2.681	3.
13	1.350	1.771	2.160	2.650	3.
14	1.345	1.761	2.145	2.624	2.
15	1.341	1.753	2.131	2.602	2.
16	1.337	1.746	2.120	2.583	2.
17	1.333	1.740	2.110	2.567	2.
18	1.330	1.734	2.101	2.552	2.
19	1.328	1.729	2.093	2.539	2.
20	1.325	1.725	2.086	2.528	2.
21	1.323	1.721	2.080	2.518	2.
22	1.321	1.717	2.074	2.508	2.
23	1.319	1.714	2.069	2.500	2.
24	1.318	1.711	2.064	2.492	2.
25	1.316	1.708	2.060	2.485	2.
26	1.315	1.706	2.056	2.479	2.
27	1.314	1.703	2.052	2.473	2.
28	1.313	1.701	2.048	2.467	2.
29	1.311	1.699	2.045	2.462	2.
30	1.310	1.697	2.042	2.457	2.

Why do we reject H_0 if t > cv?

If the calculated value for t is greater than the critical value, we reject H0.

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.

Significance (α) (confidence = 1-α)

df	0.10	0.05	0.025	0.01	0.005
1	3.078	6.314	[illegible]	[illegible]	63.657
2	1.886	2.920	[illegible]	[illegible]	9.925
3	1.638	2.353	[illegible]	[illegible]	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	[illegible]
24	1.318	[illegible]	[illegible]	[illegible]	[illegible]
25	1.316	1.708	2.060	2.485	[illegible]

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_o = "There is no significant difference"

df = (total)-2 =

P =

∴ 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
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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_o = "There is no significant difference"

df = (total)-2 = (16+15)-2 = 29

P = 0.05

∴ critical value = 1.699

t		cv
1.61	<	1.699

∴ <u>accept</u> 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
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
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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. 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
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. 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_o = "There is no significant difference"

df = (total)-2 = (10 + 12)-2 = 20

P = 0.05

∴ critical value = 1.725

t　　　cv

3.65 > 1.699

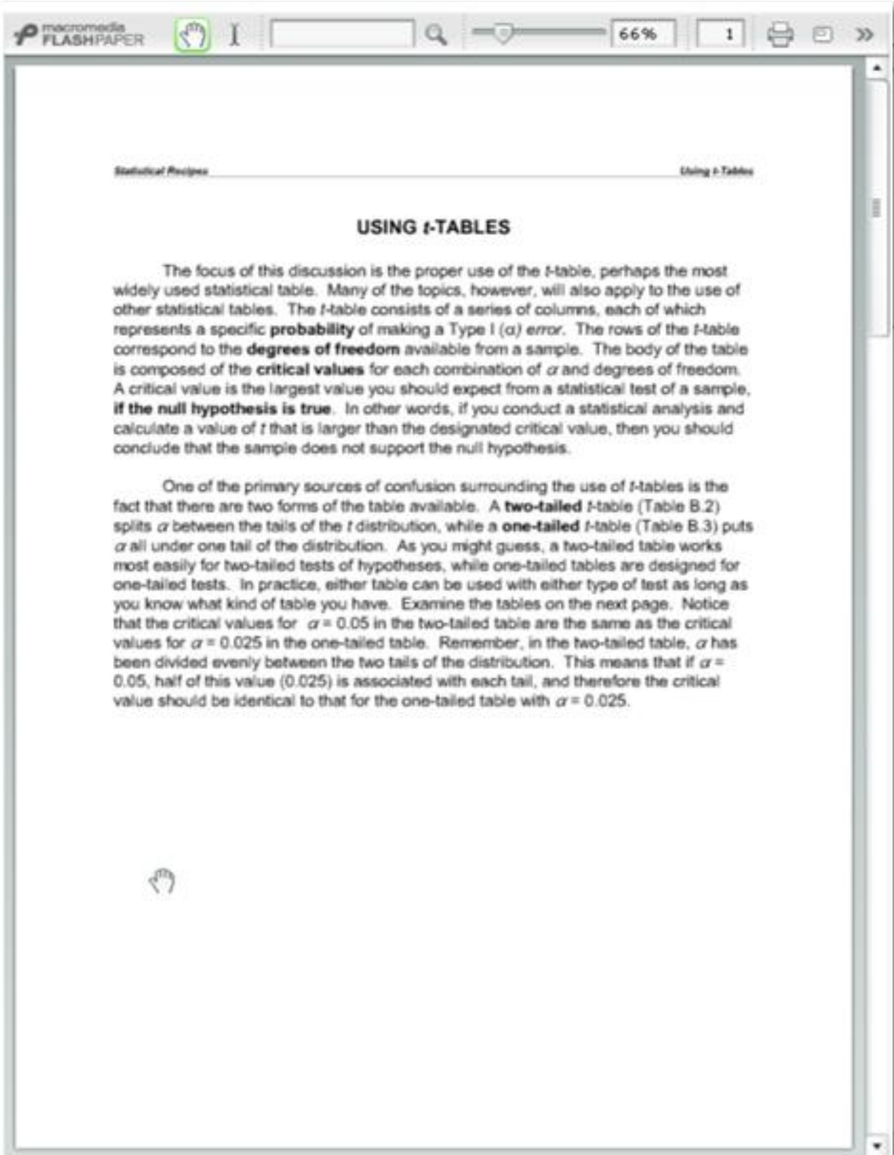
∴ reject H_0

"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
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

Some more awesome t-test resources:



Statistical Recipes — Using t-Tables

USING t-TABLES

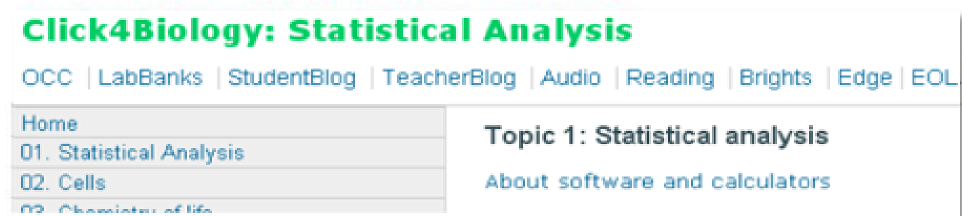
The focus of this discussion is the proper use of the t-table, perhaps the most widely used statistical table. Many of the topics, however, will also apply to the use of other statistical tables. The t-table consists of a series of columns, each of which represents a specific **probability** of making a Type I (α) *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 α 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 α between the tails of the t distribution, while a **one-tailed** t-table (Table B.3) puts α 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, α 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

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

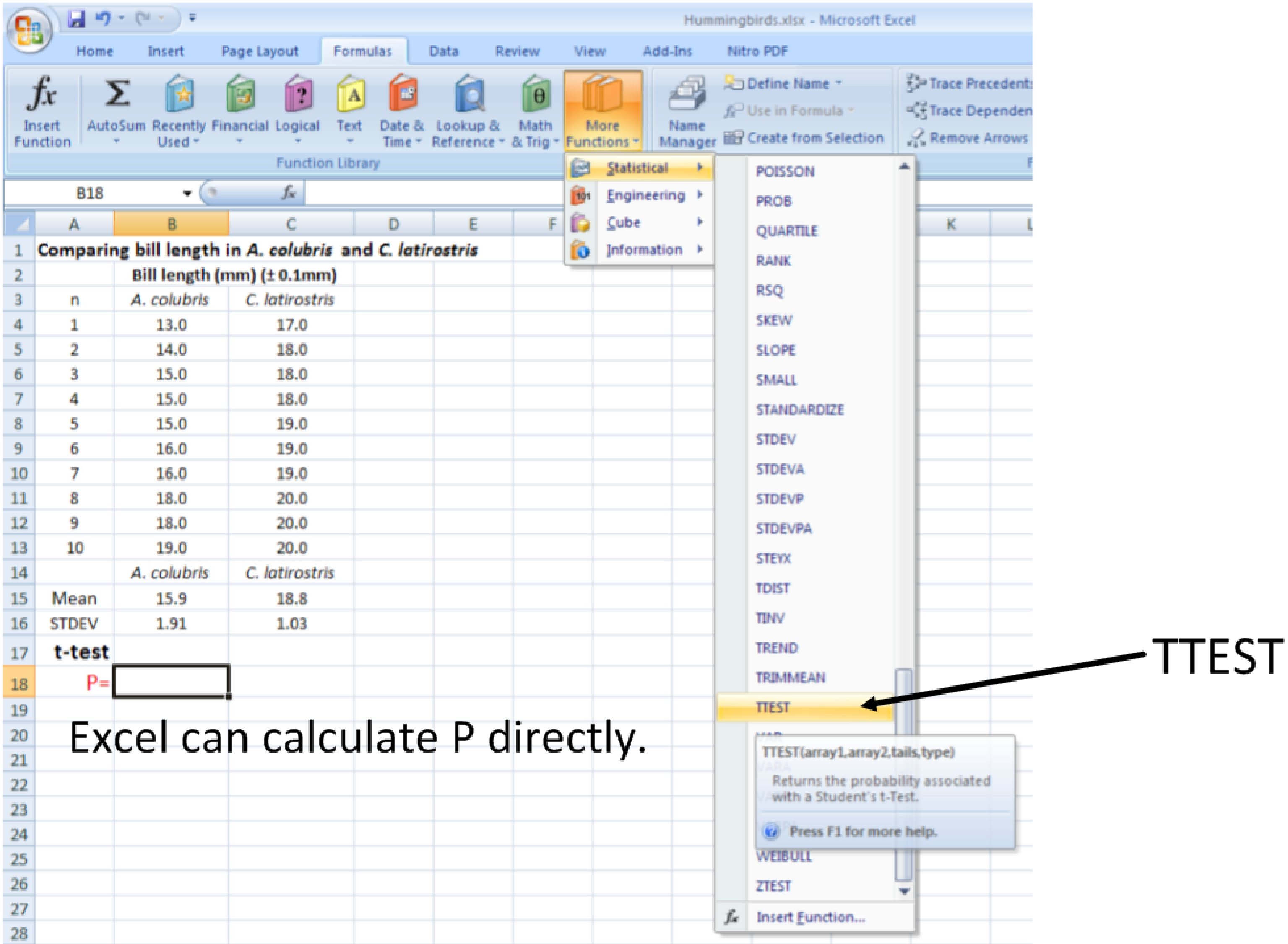
http://udel.edu/~mcdonald/statttest.html



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

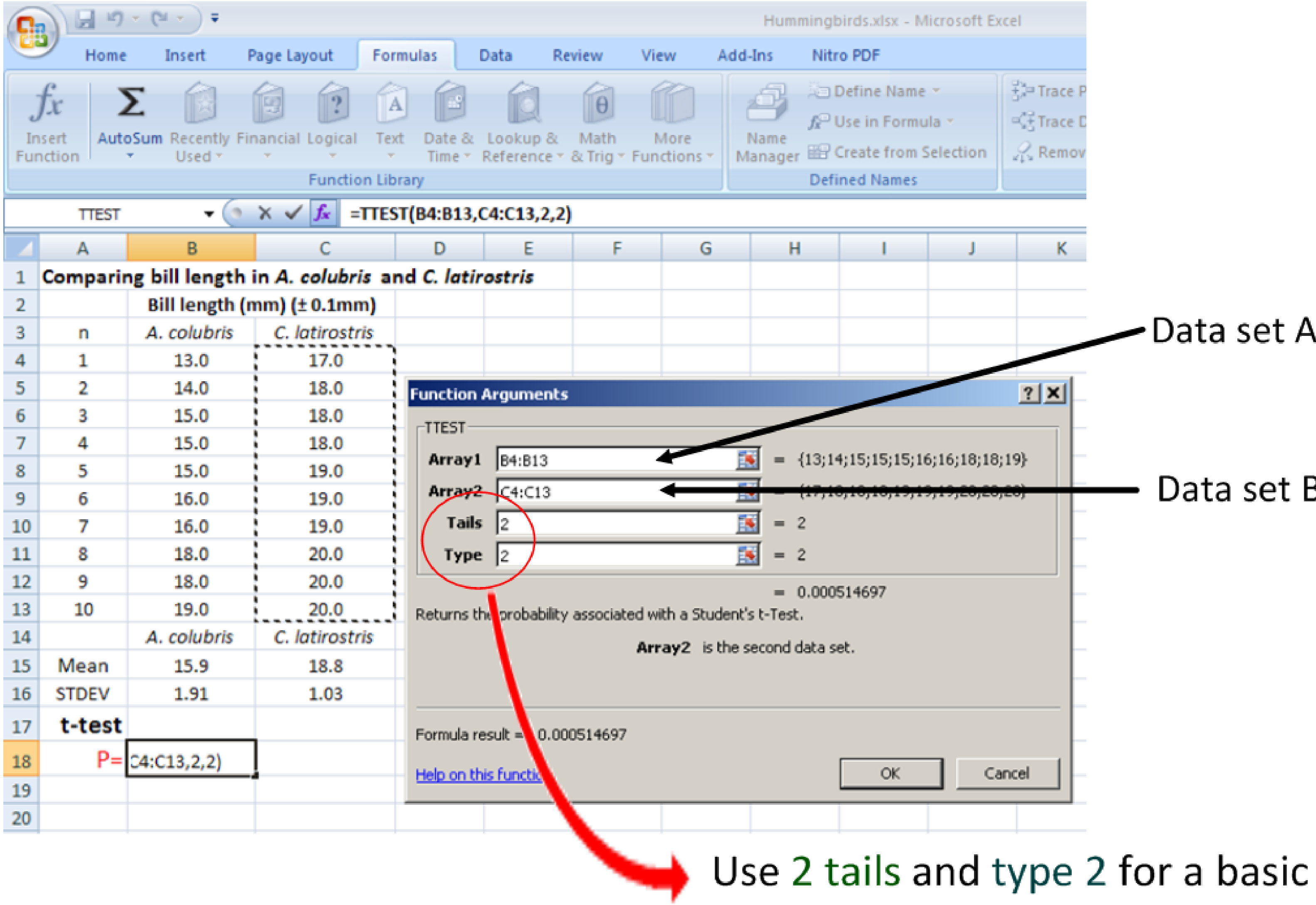
Carrying out the T-test in Excel

(This will be useful for investigations)



Carrying out the T-test in Excel

(This will be useful for investigations)



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

Carrying out the T-test in Excel

(This will be useful for investigations)

Interpreting the results

	A	B	C	D	E
1	**Comparing bill length in *A. colubris* and *C. latirostris***				
2		**Bill length (mm) (± 0.1mm)**			
3	n	*A. colubris*	*C. latirostris*		
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		*A. colubris*	*C. latirostris*		
15	Mean	15.9	18.8		
16	STDEV	1.91	1.03		
17	**t-test**				
18	H_0 = There is no significant difference				
19	P=	0.000514697			
20					
21	**P < 0.05**				
22	Therefore reject H_0				
23	There is a signiifcant difference in bill length				
24	between *A. colubris* and *C. latirostris*				
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:

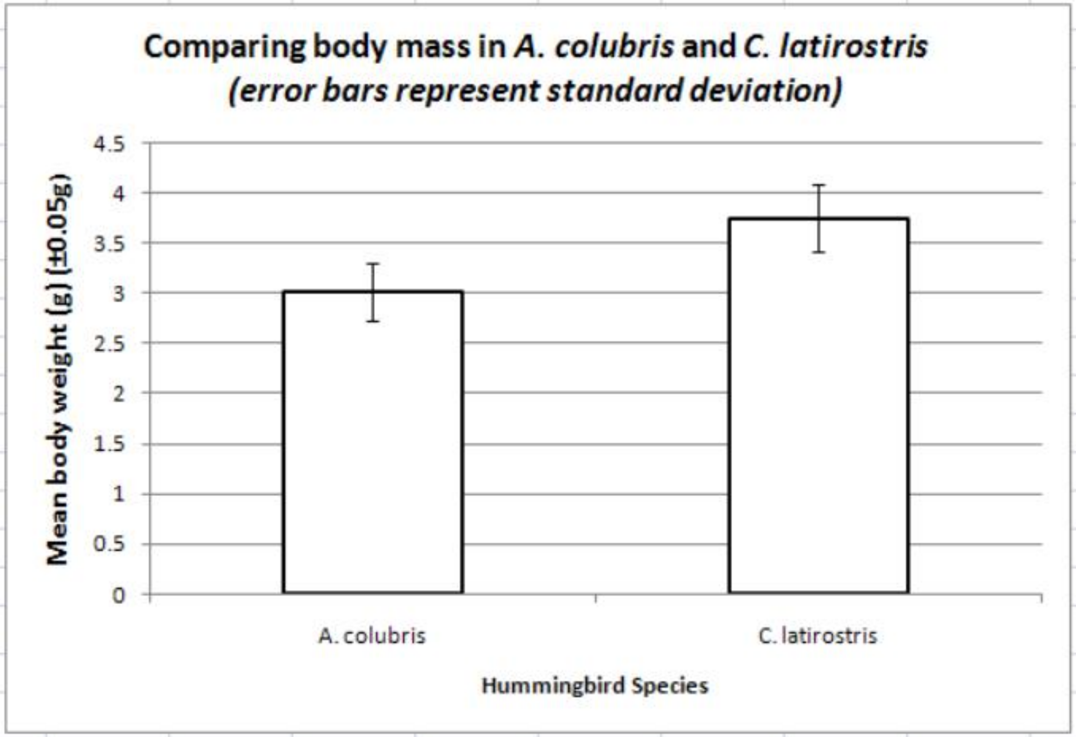
If $P < 0.05$, reject H_0

(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?

Comparing body weight in *A. colubris* and *C. latirostris*		
	Body weight (g) (± 0.05g)	
n	*A. colubris*	*C. latirostris*
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
10	3.6	4.1
	A. colubris	*C. latirostris*
Mean	3.01	3.75
STDEV	0.284604989	0.327448045
t-test		
H_0 = There is no significant difference		
P=	0.0000399	
$P < 0.05$		
Therefore reject H_0		
There is a signiifcant difference in body weight		
between *A. colubris* and *C. latirostris*		

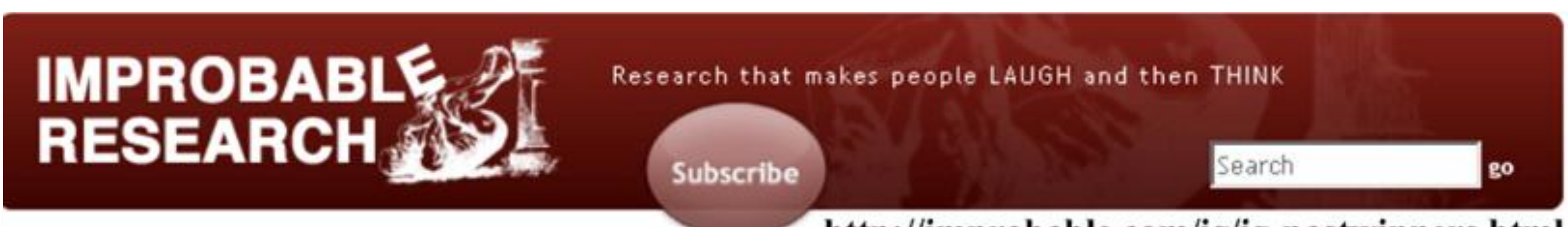


Cat Fleas vs Dog Fleas

"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.

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

Winner of the 2008 Ig Nobel prize for Biology.

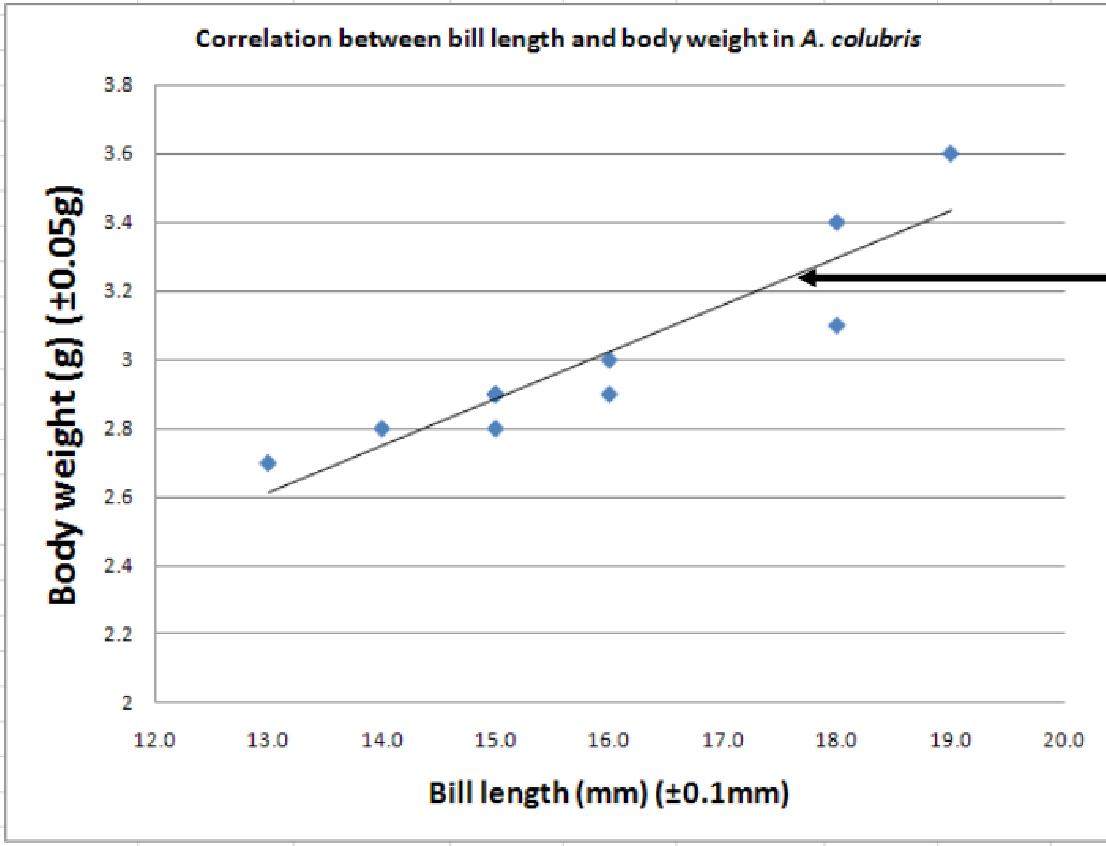


http://improbable.com/ig/ig-pastwinners.html

Correlations can suggest relationships between sets of data:

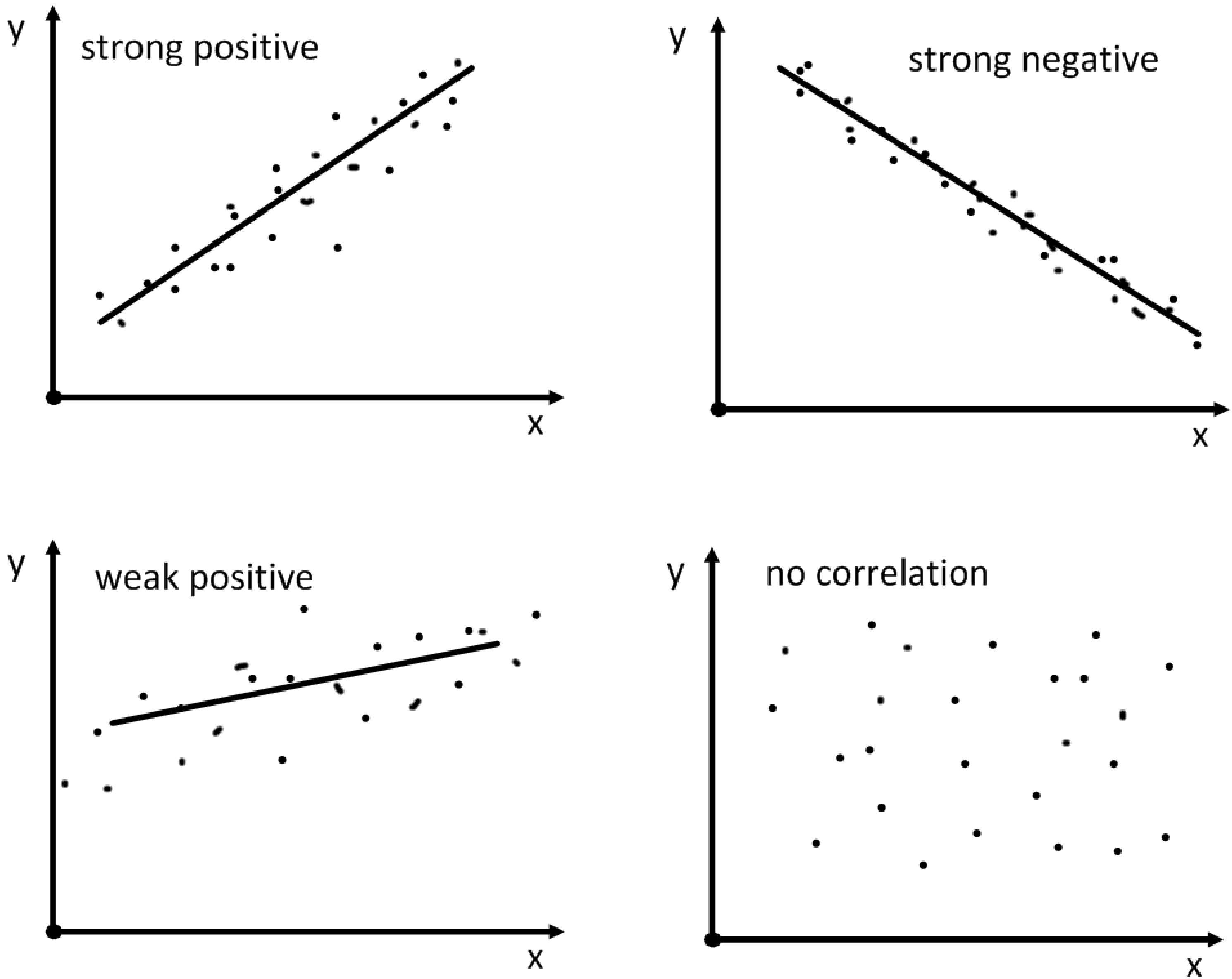
Comparing bill length and body weight in *A. colubris*

bill length	13.0	14.0	15.0	15.0	15.0	16.0	16.0	18.0	18.0	19.0
weight	2.7	2.8	2.8	2.9	2.9	2.9	3	3.1	3.4	3.6



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

Examples of correlations:



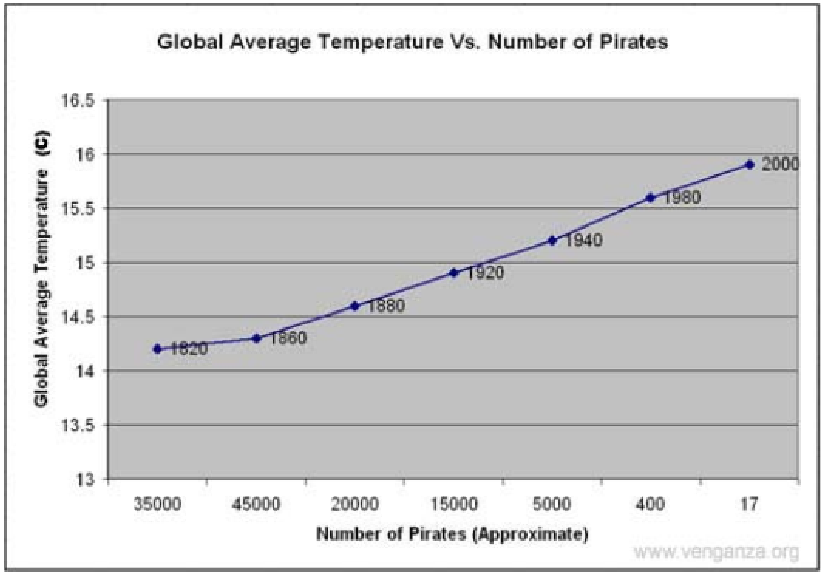
But correlations do not prove causality!

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.

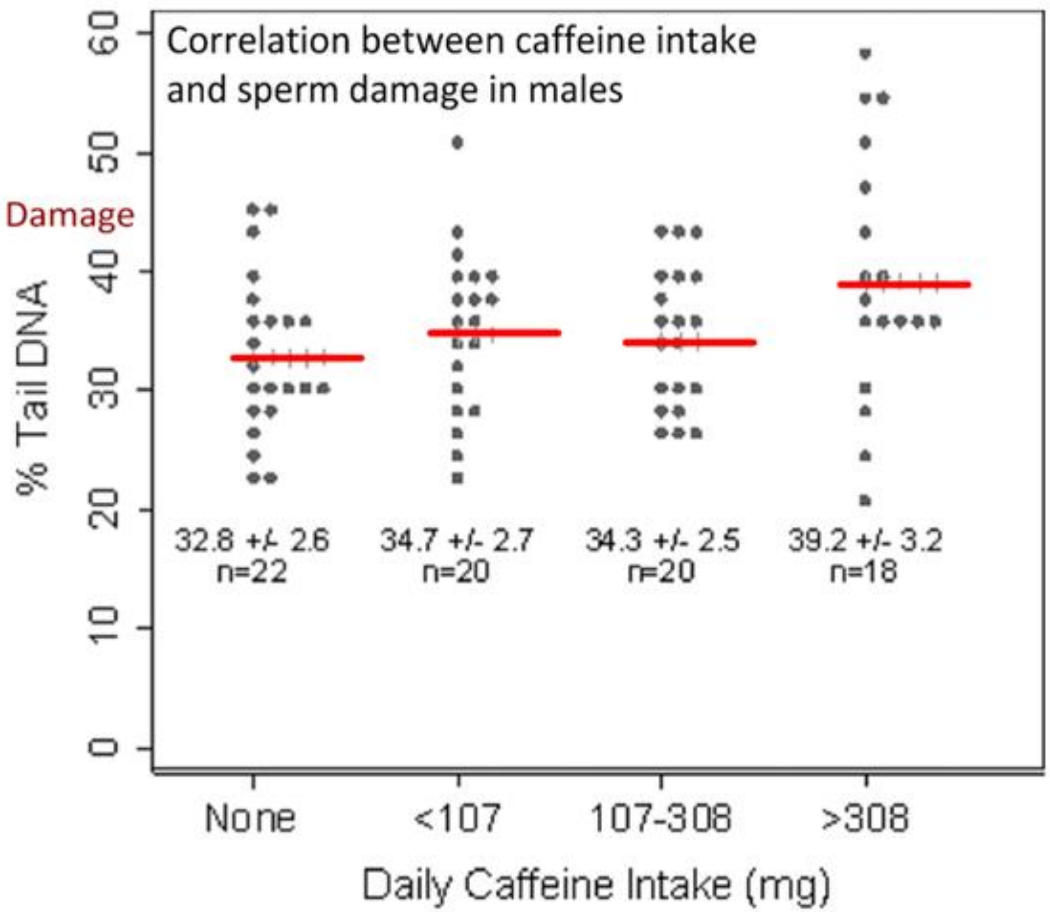
Some causal relationships:
- Temperature vs enzyme activity
- Concentration vs rate of diffusion
- CO_2 concentration vs rate of photosynthesis

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



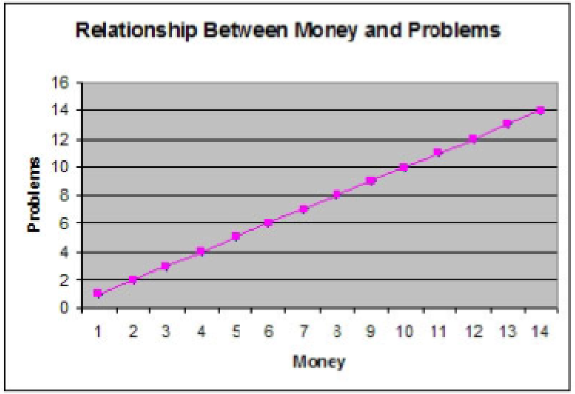
Clearly no causal relationship!
http://www.venganza.org/about/open-letter/

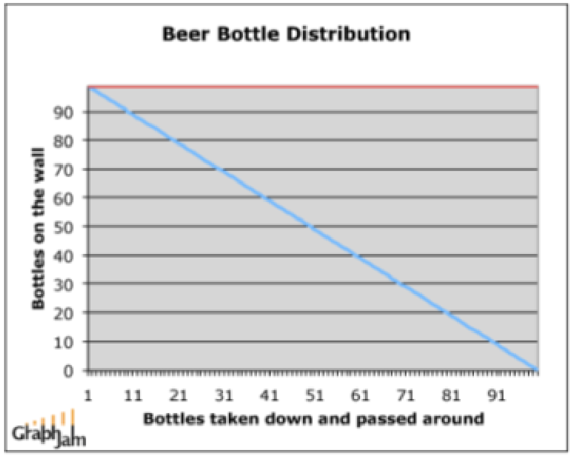
Go easy on the coffee, boys!



http://humrep.oxfordjournals.org/cgi/content/full/22/1/180

Funny graphs:





http://graphjam.com/

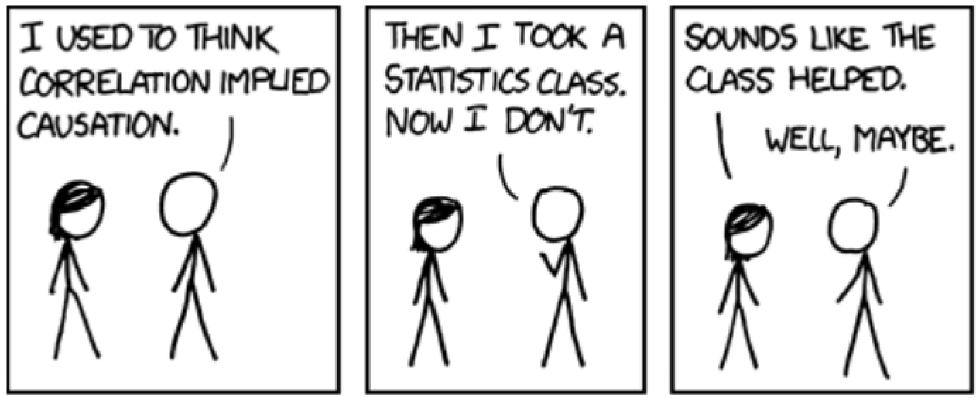
How could you test the causality of this relationship?

Try out this for amazing human population statistics:

http://graphs.gapminder.org/

See the talk here:

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



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

For more IB Biology resources:

http://sciencevideos.wordpress.com