

Statistics with Spa OWS

Lecture 5

Julia Schroeder

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Outline

- Check-in: 95CI
- T-test
- Conventions: how to report t-test?

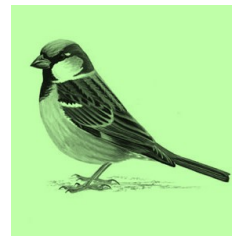
What are statistics?

- We want to know if a null hypothesis is rejected
- Most of the time, we want to know if data is distributed according to what we believe it should be distributed, given what we know

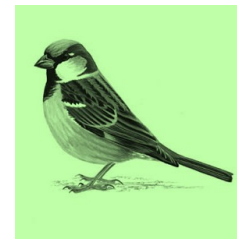
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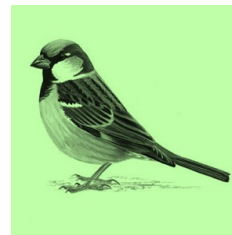
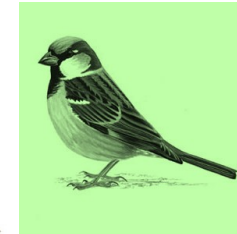
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- We will test is the mean of the
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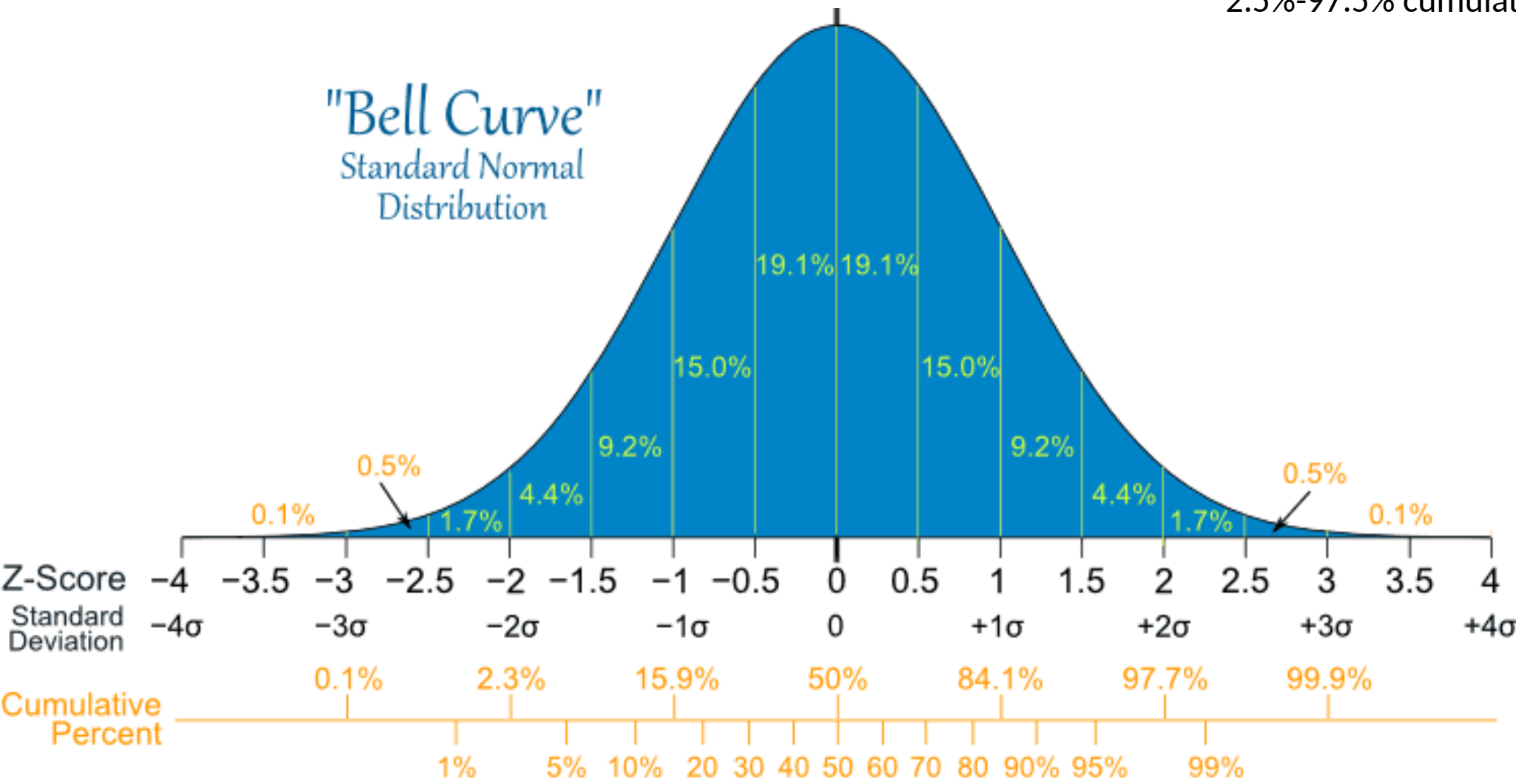
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- Most of the time, we want to know if data is distributed according to what we believe it should be distributed, given what we know
- We will test is the mean of the
- 2001 data truthfully represents the
- complete population.
- We will test if 2001 mean is within
- a certain range of values



Hypothesis testing

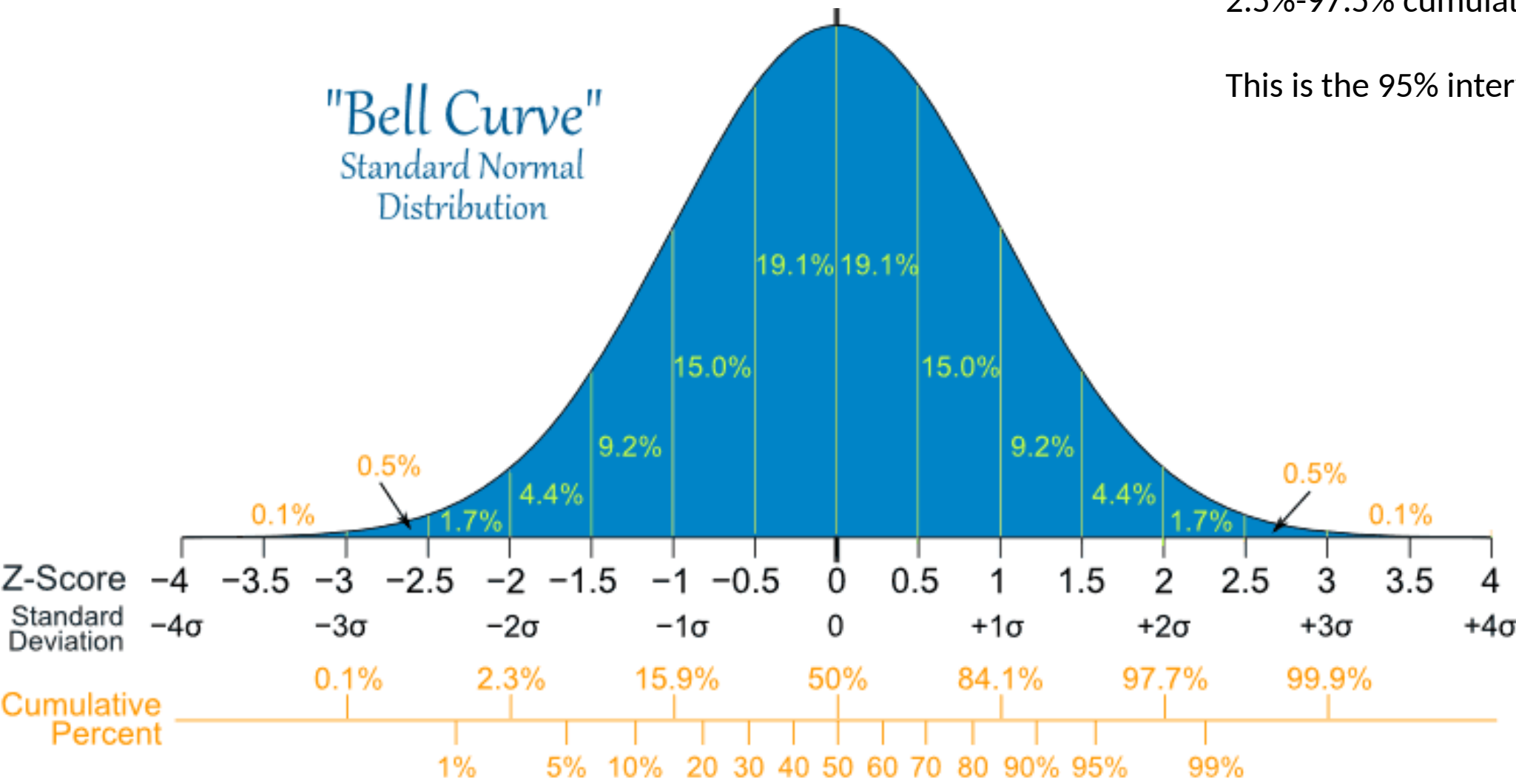
- H_0 = true mean is equal to mean of 2001
- H_1 = true mean is not equal to mean of 2001

We accept every mean within 95% of the distribution
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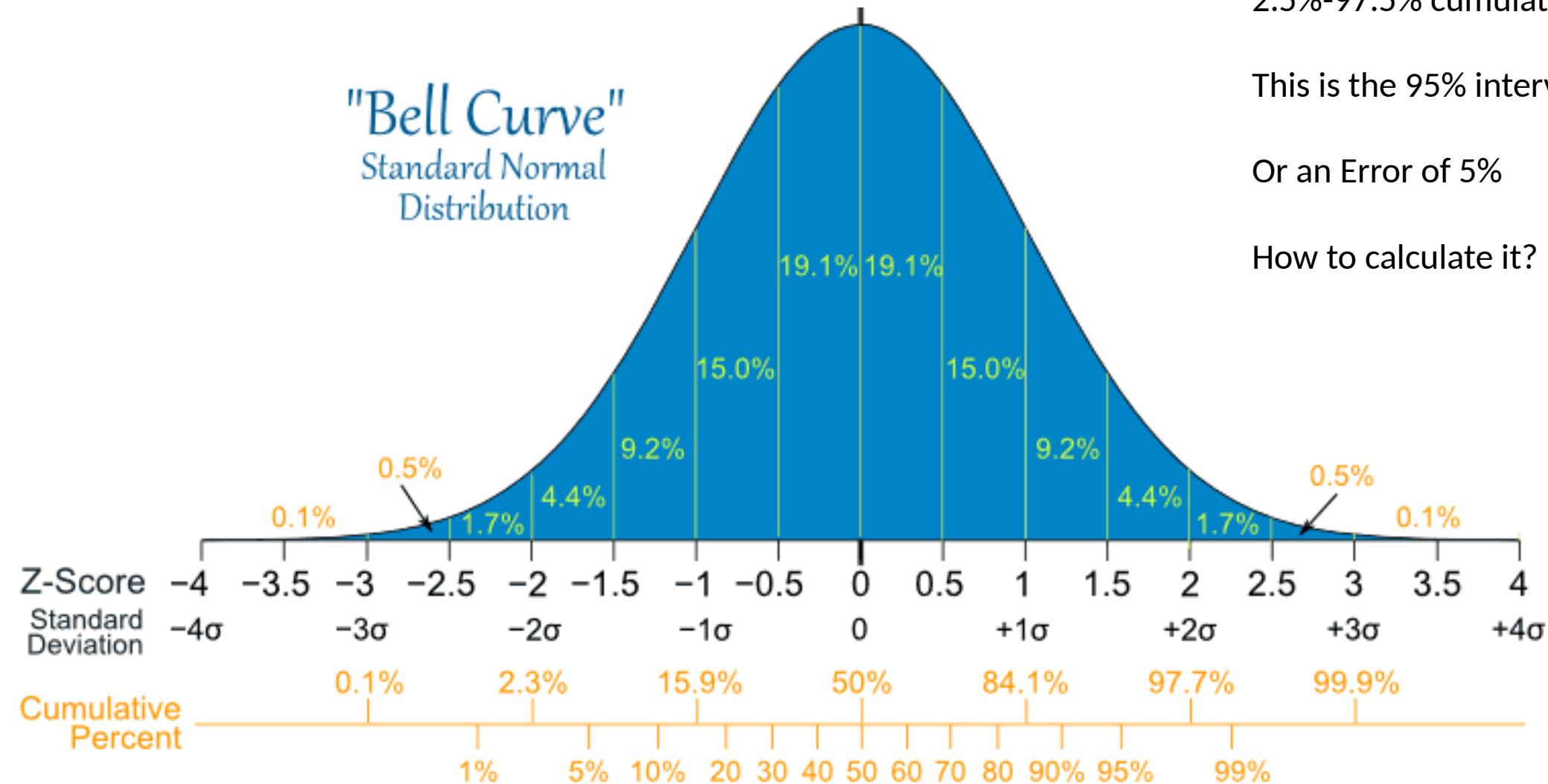
"Bell Curve"
Standard Normal
Distribution

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This is the 95% interval.

Or an Error of 5%

How to calculate it?

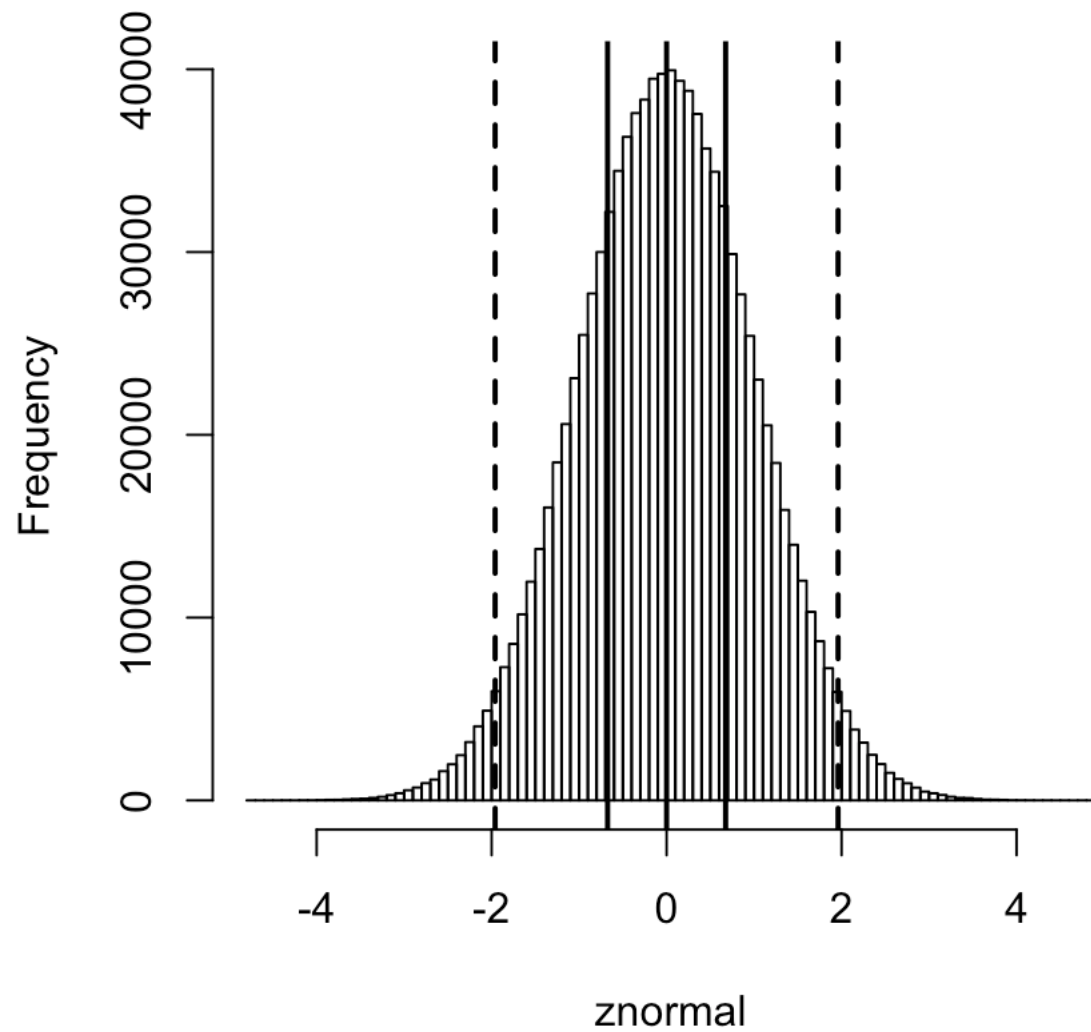


$$CI_{95\%} = \pm 1.96 \frac{s}{\sqrt{n}}$$

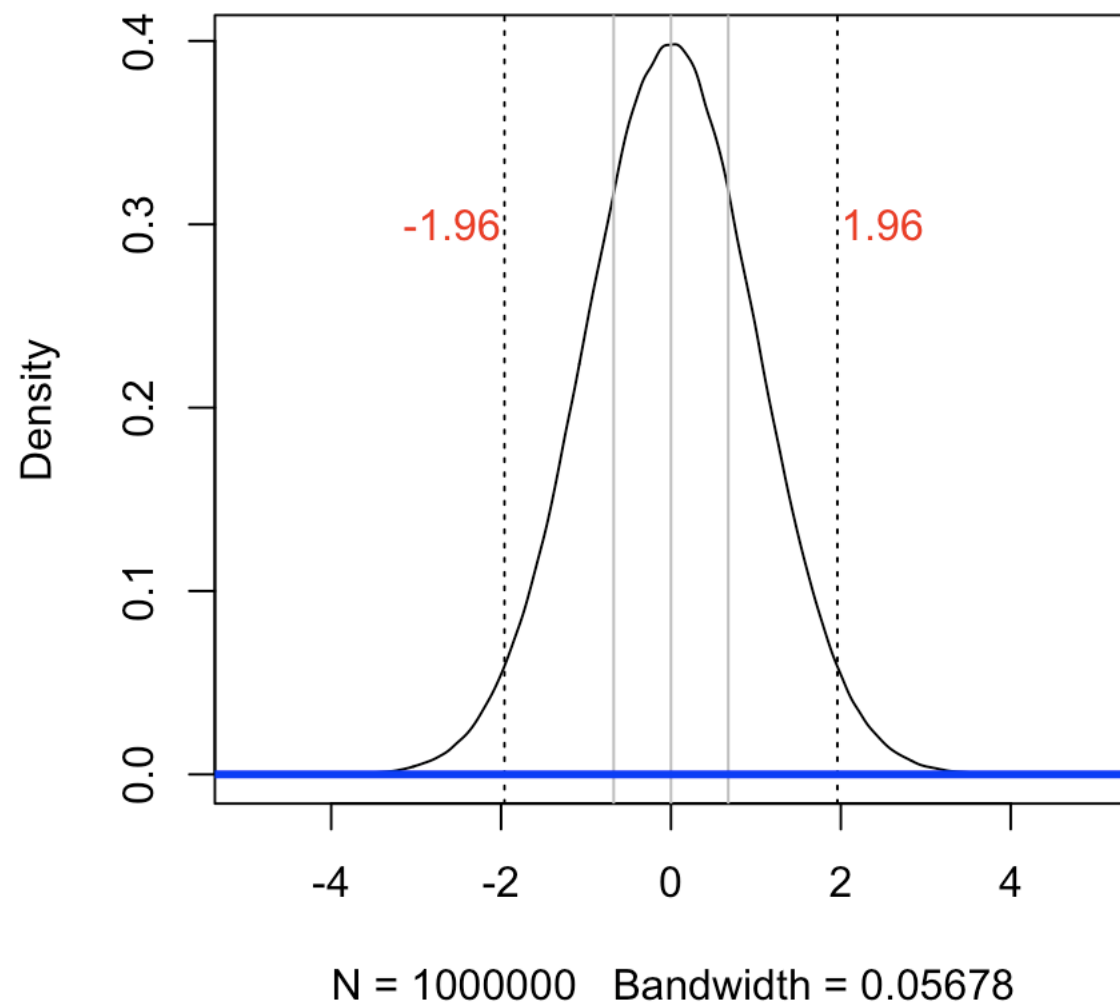
$$CI_{95\%} = \pm 1.96 \frac{s}{\sqrt{n}}$$

It is the mean plus/minus 1.96 times the standard deviation divided by the square root of the sample size

Histogram of znormal



density.default(x = znormal)



Looks familiar?

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Rule-of-thumb:
Twice the SE!

$$se = \sqrt{\frac{s^2}{n}}$$
$$se = \frac{s}{\sqrt{n}}$$

Remember:

| | Tarsus | Tarsus 2001 |
|--------------------|--------|-------------|
| Variance | 0.74 | 0.72 |
| Standard deviation | 0.86 | 0.85 |
| N | 1685 | 168 |
| Standard error | 0.02 | 0.07 |
| Mean | 18.52 | 18.19 |

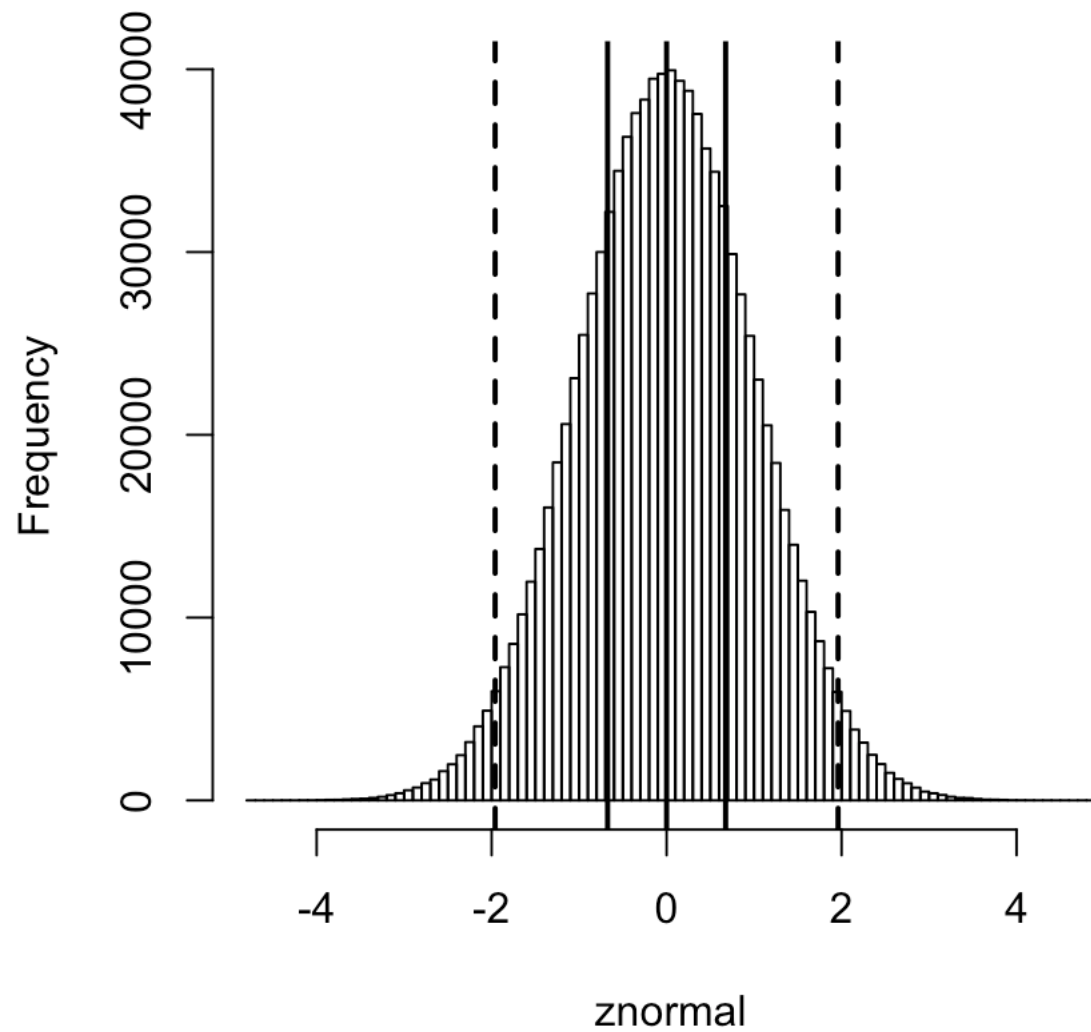
Remember:

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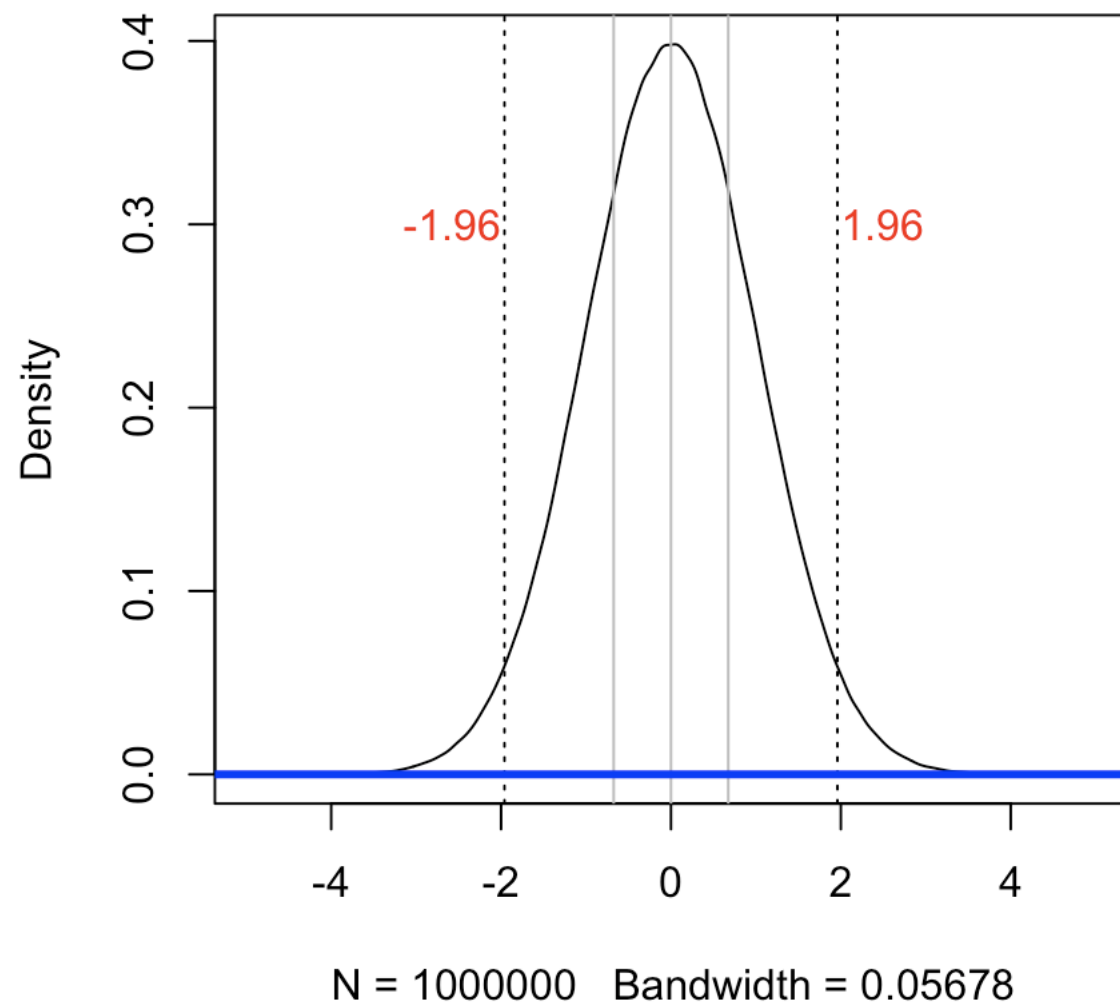
Is the sample from 2001 representative of the whole population?

Does the mean of 2001 fall within all possible means of the true distribution? We allow an error of 5%.

Histogram of znormal



density.default(x = znormal)



- Let's test this!

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| Mean | 18.52 | 18.19 |
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NO! We reject H_0 !

T-test

- H_0 = true mean is equal to 18.5
- H_1 = true mean is not equal to 18.5

$$t_{\hat{\beta}} = \frac{\hat{\beta} - \beta_0}{\text{s. e.}(\hat{\beta})}$$

- Sample size is 168, thus $df = 167$

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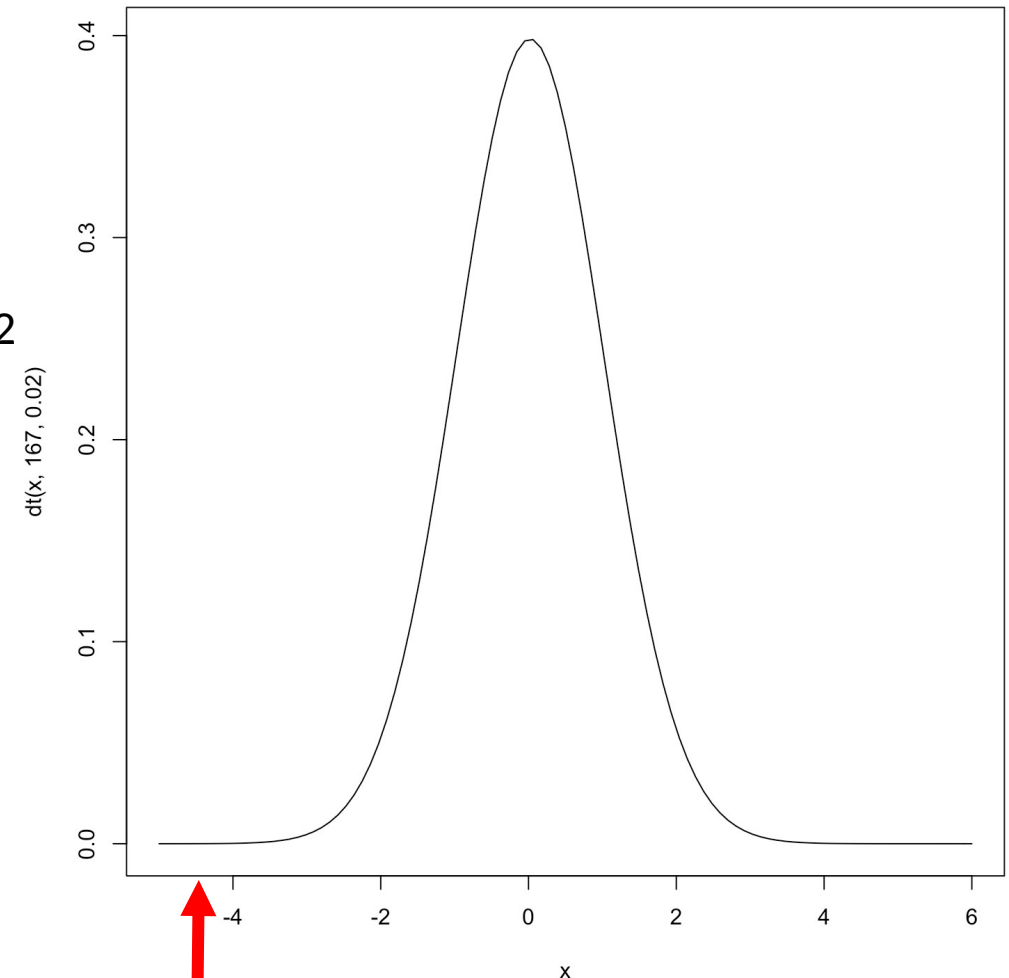
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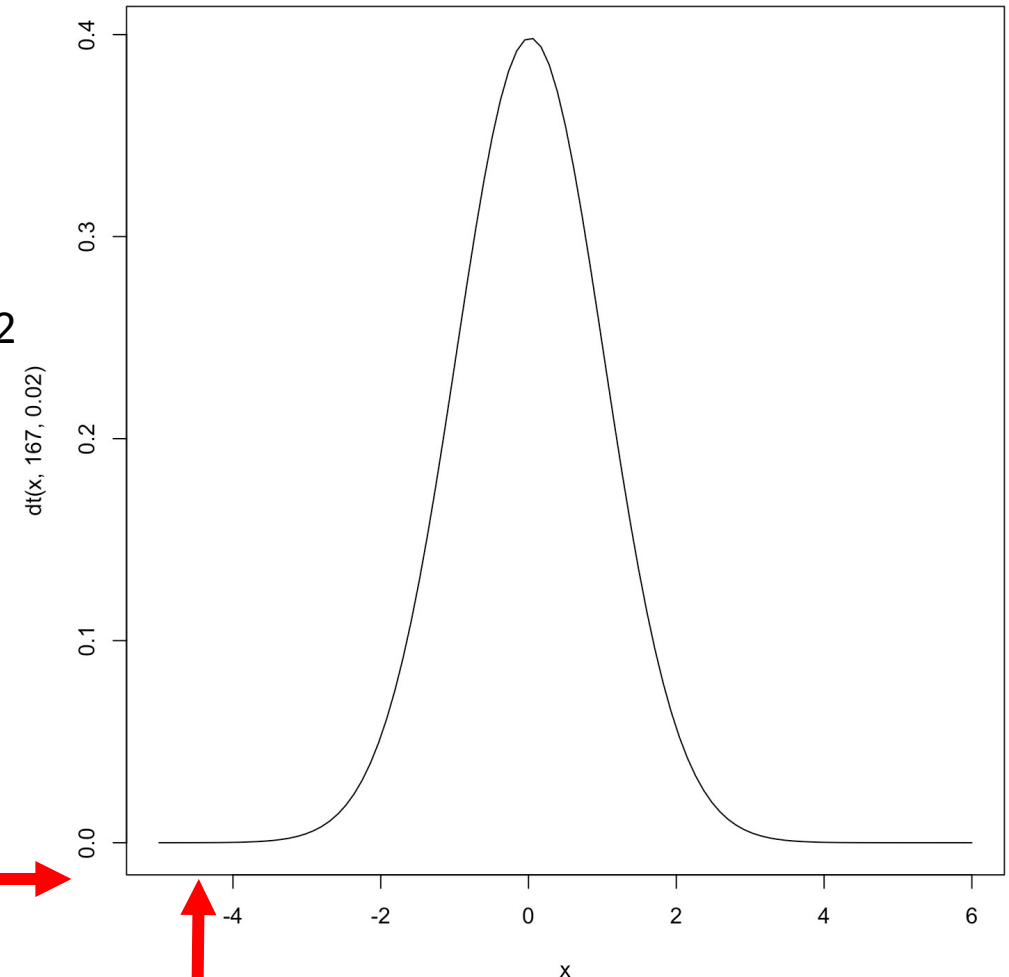
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- Sample size is 168, thus $df = 167$

p-value

TABLE of CRITICAL VALUES for STUDENT'S t DISTRIBUTIONS

Column headings denote probabilities (α) **above** tabulated values.

| d.f. | 0.40 | 0.25 | 0.10 | 0.05 | 0.04 | 0.025 | 0.02 | 0.01 | 0.005 | 0.0025 | 0.001 | 0.0005 |
|------|-------|-------|-------|-------|-------|--------|--------|--------|--------|---------|---------|---------|
| 1 | 0.325 | 1.000 | 3.078 | 6.314 | 7.916 | 12.706 | 15.894 | 31.821 | 63.656 | 127.321 | 318.289 | 636.555 |
| 2 | 0.289 | 0.816 | 1.886 | 2.920 | 3.320 | 4.303 | 4.849 | 6.965 | 9.925 | 14.089 | 22.328 | 31.821 |
| 3 | 0.277 | 0.765 | 1.638 | 2.353 | 2.605 | 3.182 | 3.482 | 4.541 | 5.841 | 7.453 | 10.214 | 12.924 |
| 4 | 0.271 | 0.741 | 1.533 | 2.132 | 2.333 | 2.776 | 2.999 | 3.747 | 4.604 | 5.598 | 7.173 | 8.608 |
| 5 | 0.267 | 0.727 | 1.476 | 2.015 | 2.191 | 2.571 | 2.757 | 3.365 | 4.032 | 4.773 | 5.894 | 6.908 |
| 6 | 0.265 | 0.718 | 1.440 | 1.943 | 2.104 | 2.447 | 2.612 | 3.143 | 3.707 | 4.317 | 5.208 | 5.959 |
| 7 | 0.263 | 0.711 | 1.415 | 1.895 | 2.046 | 2.365 | 2.517 | 2.998 | 3.499 | 4.029 | 4.785 | 5.401 |
| 8 | 0.262 | 0.706 | 1.397 | 1.860 | 2.004 | 2.306 | 2.449 | 2.896 | 3.355 | 3.833 | 4.501 | 5.041 |
| 9 | 0.261 | 0.703 | 1.383 | 1.833 | 1.973 | 2.262 | 2.398 | 2.821 | 3.250 | 3.690 | 4.297 | 4.759 |
| 10 | 0.260 | 0.700 | 1.372 | 1.812 | 1.948 | 2.228 | 2.359 | 2.764 | 3.169 | 3.581 | 4.144 | 4.599 |
| 11 | 0.260 | 0.697 | 1.363 | 1.796 | 1.928 | 2.201 | 2.328 | 2.718 | 3.106 | 3.497 | 4.025 | 4.477 |
| 12 | 0.259 | 0.695 | 1.356 | 1.782 | 1.912 | 2.179 | 2.303 | 2.681 | 3.055 | 3.428 | 3.930 | 4.383 |
| 13 | 0.259 | 0.694 | 1.350 | 1.771 | 1.899 | 2.160 | 2.282 | 2.650 | 3.012 | 3.372 | 3.852 | 4.318 |
| 14 | 0.258 | 0.692 | 1.345 | 1.761 | 1.887 | 2.145 | 2.264 | 2.624 | 2.977 | 3.326 | 3.787 | 4.266 |
| 15 | 0.258 | 0.691 | 1.341 | 1.753 | 1.878 | 2.131 | 2.249 | 2.602 | 2.947 | 3.286 | 3.733 | 4.224 |
| 16 | 0.258 | 0.690 | 1.337 | 1.746 | 1.869 | 2.120 | 2.235 | 2.583 | 2.921 | 3.252 | 3.686 | 4.187 |
| 17 | 0.257 | 0.689 | 1.333 | 1.740 | 1.862 | 2.110 | 2.224 | 2.567 | 2.898 | 3.222 | 3.646 | 4.153 |
| 18 | 0.257 | 0.688 | 1.330 | 1.734 | 1.855 | 2.101 | 2.214 | 2.552 | 2.878 | 3.197 | 3.610 | 4.122 |
| 19 | 0.257 | 0.688 | 1.328 | 1.729 | 1.850 | 2.093 | 2.205 | 2.539 | 2.861 | 3.174 | 3.579 | 4.094 |
| 20 | 0.257 | 0.687 | 1.325 | 1.725 | 1.844 | 2.086 | 2.197 | 2.528 | 2.845 | 3.153 | 3.552 | 4.069 |
| 21 | 0.257 | 0.686 | 1.323 | 1.721 | 1.840 | 2.080 | 2.189 | 2.518 | 2.831 | 3.135 | 3.527 | 4.046 |
| 22 | 0.256 | 0.686 | 1.321 | 1.717 | 1.835 | 2.074 | 2.183 | 2.508 | 2.819 | 3.119 | 3.505 | 4.024 |
| 23 | 0.256 | 0.685 | 1.319 | 1.714 | 1.832 | 2.069 | 2.177 | 2.500 | 2.807 | 3.104 | 3.485 | 4.003 |
| 24 | 0.256 | 0.685 | 1.318 | 1.711 | 1.828 | 2.064 | 2.172 | 2.492 | 2.797 | 3.091 | 3.467 | 4.000 |
| 25 | 0.256 | 0.684 | 1.316 | 1.708 | 1.825 | 2.060 | 2.167 | 2.485 | 2.787 | 3.078 | 3.450 | 4.000 |
| 26 | 0.256 | 0.684 | 1.315 | 1.706 | 1.822 | 2.056 | 2.162 | 2.479 | 2.779 | 3.067 | 3.435 | 4.000 |
| 27 | 0.256 | 0.684 | 1.314 | 1.703 | 1.819 | 2.052 | 2.158 | 2.473 | 2.771 | 3.057 | 3.421 | 4.000 |
| 28 | 0.256 | 0.683 | 1.313 | 1.701 | 1.817 | 2.048 | 2.154 | 2.467 | 2.763 | 3.047 | 3.408 | 4.000 |
| 29 | 0.256 | 0.683 | 1.311 | 1.699 | 1.814 | 2.045 | 2.150 | 2.462 | 2.756 | 3.038 | 3.396 | 4.000 |
| 30 | 0.256 | 0.683 | 1.310 | 1.697 | 1.812 | 2.042 | 2.147 | 2.457 | 2.750 | 3.030 | 3.385 | 4.000 |
| 31 | 0.256 | 0.682 | 1.309 | 1.696 | 1.810 | 2.040 | 2.144 | 2.453 | 2.744 | 3.022 | 3.375 | 4.000 |
| 32 | 0.255 | 0.682 | 1.309 | 1.694 | 1.808 | 2.037 | 2.141 | 2.449 | 2.738 | 3.015 | 3.365 | 4.000 |
| 33 | 0.255 | 0.682 | 1.308 | 1.692 | 1.806 | 2.035 | 2.138 | 2.445 | 2.733 | 3.008 | 3.356 | 4.000 |
| 34 | 0.255 | 0.682 | 1.307 | 1.691 | 1.805 | 2.032 | 2.136 | 2.441 | 2.728 | 3.002 | 3.348 | 4.000 |
| 35 | 0.255 | 0.682 | 1.306 | 1.690 | 1.803 | 2.030 | 2.133 | 2.438 | 2.724 | 2.996 | 3.340 | 4.000 |
| 36 | 0.255 | 0.681 | 1.306 | 1.688 | 1.802 | 2.028 | 2.131 | 2.434 | 2.719 | 2.990 | 3.333 | 4.000 |
| 37 | 0.255 | 0.681 | 1.305 | 1.687 | 1.800 | 2.026 | 2.129 | 2.431 | 2.715 | 2.985 | 3.326 | 4.000 |
| 38 | 0.255 | 0.681 | 1.304 | 1.686 | 1.799 | 2.024 | 2.127 | 2.429 | 2.712 | 2.980 | 3.319 | 4.000 |
| 39 | 0.255 | 0.681 | 1.304 | 1.685 | 1.798 | 2.023 | 2.125 | 2.426 | 2.708 | 2.976 | 3.313 | 4.000 |
| 40 | 0.255 | 0.681 | 1.303 | 1.684 | 1.796 | 2.021 | 2.123 | 2.423 | 2.704 | 2.971 | 3.307 | 4.000 |
| 60 | 0.254 | 0.679 | 1.296 | 1.671 | 1.781 | 2.000 | 2.099 | 2.390 | 2.660 | 2.915 | 3.232 | 4.000 |
| 80 | 0.254 | 0.678 | 1.292 | 1.664 | 1.773 | 1.990 | 2.088 | 2.374 | 2.639 | 2.887 | 3.195 | 4.000 |
| 100 | 0.254 | 0.677 | 1.290 | 1.660 | 1.769 | 1.984 | 2.081 | 2.364 | 2.626 | 2.871 | 3.174 | 4.000 |
| 120 | 0.254 | 0.677 | 1.289 | 1.658 | 1.766 | 1.980 | 2.076 | 2.358 | 2.617 | 2.860 | 3.160 | 4.000 |
| 140 | 0.254 | 0.676 | 1.288 | 1.656 | 1.763 | 1.977 | 2.073 | 2.353 | 2.611 | 2.852 | 3.149 | 4.000 |
| 160 | 0.254 | 0.676 | 1.287 | 1.654 | 1.762 | 1.975 | 2.071 | 2.350 | 2.607 | 2.847 | 3.142 | 4.000 |
| 180 | 0.254 | 0.676 | 1.286 | 1.653 | 1.761 | 1.973 | 2.069 | 2.347 | 2.603 | 2.842 | 3.136 | 4.000 |
| 200 | 0.254 | 0.676 | 1.286 | 1.653 | 1.760 | 1.972 | 2.067 | 2.345 | 2.601 | 2.838 | 3.131 | 4.000 |
| 250 | 0.254 | 0.675 | 1.285 | 1.651 | 1.758 | 1.969 | 2.065 | 2.341 | 2.596 | 2.832 | 3.123 | 4.000 |
| inf | 0.253 | 0.674 | 1.282 | 1.645 | 1.751 | 1.960 | 2.054 | 2.326 | 2.576 | 2.807 | 3.090 | 4.000 |

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| 2 | 0.289 | 0.816 | 1.886 | 2.920 | 3.320 | 4.303 | 4.849 | 6.965 | 9.925 | 14.089 | 22.328 | 31.821 |
| 3 | 0.277 | 0.765 | 1.638 | 2.353 | 2.605 | 3.182 | 3.482 | 4.541 | 5.841 | 7.453 | 10.214 | 12.924 |
| 4 | 0.271 | 0.741 | 1.533 | 2.132 | 2.333 | 2.776 | 2.999 | 3.747 | 4.604 | 5.598 | 7.173 | 8.608 |
| 5 | 0.267 | 0.727 | 1.476 | 2.015 | 2.191 | 2.571 | 2.757 | 3.365 | 4.032 | 4.773 | 5.894 | 6.908 |
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| 8 | 0.262 | 0.706 | 1.397 | 1.860 | 2.004 | 2.306 | 2.449 | 2.896 | 3.355 | 3.833 | 4.501 | 5.041 |
| 9 | 0.261 | 0.703 | 1.383 | 1.833 | 1.973 | 2.262 | 2.398 | 2.821 | 3.250 | 3.690 | 4.297 | 4.759 |
| 10 | 0.260 | 0.700 | 1.372 | 1.812 | 1.948 | 2.228 | 2.359 | 2.764 | 3.169 | 3.581 | 4.144 | 4.608 |
| 11 | 0.260 | 0.697 | 1.363 | 1.796 | 1.928 | 2.201 | 2.328 | 2.718 | 3.106 | 3.497 | 4.025 | 4.479 |
| 12 | 0.259 | 0.695 | 1.356 | 1.782 | 1.912 | 2.179 | 2.303 | 2.681 | 3.055 | 3.428 | 3.930 | 4.353 |
| 13 | 0.259 | 0.694 | 1.350 | 1.771 | 1.899 | 2.160 | 2.282 | 2.650 | 3.012 | 3.372 | 3.852 | 4.256 |
| 14 | 0.258 | 0.692 | 1.345 | 1.761 | 1.887 | 2.145 | 2.264 | 2.624 | 2.977 | 3.326 | 3.787 | 4.177 |
| 15 | 0.258 | 0.691 | 1.341 | 1.753 | 1.878 | 2.131 | 2.249 | 2.602 | 2.947 | 3.286 | 3.733 | 4.119 |
| 16 | 0.258 | 0.690 | 1.337 | 1.746 | 1.869 | 2.120 | 2.235 | 2.583 | 2.921 | 3.252 | 3.686 | 4.069 |
| 17 | 0.257 | 0.689 | 1.333 | 1.740 | 1.862 | 2.110 | 2.224 | 2.567 | 2.898 | 3.222 | 3.646 | 4.024 |
| 18 | 0.257 | 0.688 | 1.330 | 1.734 | 1.855 | 2.101 | 2.214 | 2.552 | 2.878 | 3.197 | 3.610 | 3.989 |
| 19 | 0.257 | 0.688 | 1.328 | 1.729 | 1.850 | 2.093 | 2.205 | 2.539 | 2.861 | 3.174 | 3.579 | 3.957 |
| 20 | 0.257 | 0.687 | 1.325 | 1.725 | 1.844 | 2.086 | 2.197 | 2.528 | 2.845 | 3.153 | 3.552 | 3.927 |
| 21 | 0.257 | 0.686 | 1.323 | 1.721 | 1.840 | 2.080 | 2.189 | 2.518 | 2.831 | 3.135 | 3.527 | 3.897 |
| 22 | 0.256 | 0.686 | 1.321 | 1.717 | 1.835 | 2.074 | 2.183 | 2.508 | 2.819 | 3.119 | 3.505 | 3.869 |
| 23 | 0.256 | 0.685 | 1.319 | 1.714 | 1.832 | 2.069 | 2.177 | 2.500 | 2.807 | 3.104 | 3.485 | 3.841 |
| 24 | 0.256 | 0.685 | 1.318 | 1.711 | 1.828 | 2.064 | 2.172 | 2.492 | 2.797 | 3.091 | 3.467 | 3.814 |
| 25 | 0.256 | 0.684 | 1.316 | 1.708 | 1.825 | 2.060 | 2.167 | 2.485 | 2.787 | 3.078 | 3.450 | 3.787 |
| 26 | 0.256 | 0.684 | 1.315 | 1.706 | 1.822 | 2.056 | 2.162 | 2.479 | 2.779 | 3.067 | 3.435 | 3.761 |
| 27 | 0.256 | 0.684 | 1.314 | 1.703 | 1.819 | 2.052 | 2.158 | 2.473 | 2.771 | 3.057 | 3.421 | 3.735 |
| 28 | 0.256 | 0.683 | 1.313 | 1.701 | 1.817 | 2.048 | 2.154 | 2.467 | 2.763 | 3.047 | 3.408 | 3.709 |
| 29 | 0.256 | 0.683 | 1.311 | 1.699 | 1.814 | 2.045 | 2.150 | 2.462 | 2.756 | 3.038 | 3.396 | 3.683 |
| 30 | 0.256 | 0.683 | 1.310 | 1.697 | 1.812 | 2.042 | 2.147 | 2.457 | 2.750 | 3.030 | 3.385 | 3.657 |
| 31 | 0.256 | 0.682 | 1.309 | 1.696 | 1.810 | 2.040 | 2.144 | 2.453 | 2.744 | 3.022 | 3.375 | 3.631 |
| 32 | 0.255 | 0.682 | 1.309 | 1.694 | 1.808 | 2.037 | 2.141 | 2.449 | 2.738 | 3.015 | 3.365 | 3.605 |
| 33 | 0.255 | 0.682 | 1.308 | 1.692 | 1.806 | 2.035 | 2.138 | 2.445 | 2.733 | 3.008 | 3.356 | 3.579 |
| 34 | 0.255 | 0.682 | 1.307 | 1.691 | 1.805 | 2.032 | 2.136 | 2.441 | 2.728 | 3.002 | 3.348 | 3.553 |
| 35 | 0.255 | 0.682 | 1.306 | 1.690 | 1.803 | 2.030 | 2.133 | 2.438 | 2.724 | 2.996 | 3.340 | 3.527 |
| 36 | 0.255 | 0.681 | 1.306 | 1.688 | 1.802 | 2.028 | 2.131 | 2.434 | 2.719 | 2.990 | 3.333 | 3.501 |
| 37 | 0.255 | 0.681 | 1.305 | 1.687 | 1.800 | 2.026 | 2.129 | 2.431 | 2.715 | 2.985 | 3.326 | 3.475 |
| 38 | 0.255 | 0.681 | 1.304 | 1.686 | 1.799 | 2.024 | 2.127 | 2.429 | 2.712 | 2.980 | 3.319 | 3.449 |
| 39 | 0.255 | 0.681 | 1.304 | 1.685 | 1.798 | 2.023 | 2.125 | 2.426 | 2.708 | 2.976 | 3.313 | 3.423 |
| 40 | 0.255 | 0.681 | 1.303 | 1.684 | 1.796 | 2.021 | 2.123 | 2.423 | 2.704 | 2.971 | 3.307 | 3.397 |
| 60 | 0.254 | 0.679 | 1.296 | 1.671 | 1.781 | 2.000 | 2.099 | 2.390 | 2.660 | 2.915 | 3.232 | 3.232 |
| 80 | 0.254 | 0.678 | 1.292 | 1.664 | 1.773 | 1.990 | 2.088 | 2.374 | 2.639 | 2.887 | 3.195 | 3.195 |
| 100 | 0.254 | 0.677 | 1.290 | 1.660 | 1.769 | 1.984 | 2.081 | 2.364 | 2.626 | 2.871 | 3.174 | 3.174 |
| 120 | 0.254 | 0.677 | 1.289 | 1.658 | 1.766 | 1.980 | 2.076 | 2.358 | 2.617 | 2.860 | 3.160 | 3.160 |
| 140 | 0.254 | 0.676 | 1.288 | 1.656 | 1.763 | 1.977 | 2.073 | 2.353 | 2.611 | 2.852 | 3.149 | 3.149 |
| 160 | 0.254 | 0.676 | 1.287 | 1.654 | 1.762 | 1.975 | 2.071 | 2.350 | 2.607 | 2.847 | 3.142 | 3.142 |
| 180 | 0.254 | 0.676 | 1.286 | 1.653 | 1.761 | 1.973 | 2.069 | 2.347 | 2.603 | 2.842 | 3.136 | 3.136 |
| 200 | 0.254 | 0.676 | 1.286 | 1.653 | 1.760 | 1.972 | 2.067 | 2.345 | 2.601 | 2.838 | 3.131 | 3.131 |
| 250 | 0.254 | 0.675 | 1.285 | 1.651 | 1.758 | 1.969 | 2.065 | 2.341 | 2.596 | 2.832 | 3.123 | 3.123 |
| inf | 0.253 | 0.674 | 1.282 | 1.645 | 1.751 | 1.960 | 2.054 | 2.326 | 2.576 | 2.807 | 3.090 | 3.090 |

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$$t_{\hat{\beta}} = \frac{\hat{\beta} - \beta_0}{\text{s.e.}(\hat{\beta})} = \frac{18.19 - 18.5}{0.07} = -4.42$$

- Sample size is 168, thus $df = 167$

p-value



| Column headings denote probabilities (α) above tabulated values. | | | | | | | | | | | | |
|---|-------|-------|-------|-------|-------|--------|--------|--------|--------|---------|---------|---------|
| d.f. | 0.40 | 0.25 | 0.10 | 0.05 | 0.04 | 0.025 | 0.02 | 0.01 | 0.005 | 0.0025 | 0.001 | 0.0005 |
| 1 | 0.325 | 1.000 | 3.078 | 6.314 | 7.916 | 12.706 | 15.894 | 31.821 | 63.656 | 127.321 | 318.289 | 636.564 |
| 2 | 0.289 | 0.816 | 1.886 | 2.920 | 3.320 | 4.303 | 4.849 | 6.965 | 9.925 | 14.089 | 22.328 | 31.821 |
| 3 | 0.277 | 0.765 | 1.638 | 2.353 | 2.605 | 3.182 | 3.482 | 4.541 | 5.841 | 7.453 | 10.214 | 12.924 |
| 4 | 0.271 | 0.741 | 1.533 | 2.132 | 2.333 | 2.776 | 2.999 | 3.747 | 4.604 | 5.598 | 7.173 | 8.610 |
| 5 | 0.267 | 0.727 | 1.476 | 2.015 | 2.191 | 2.571 | 2.757 | 3.365 | 4.032 | 4.773 | 5.894 | 6.965 |
| 6 | 0.265 | 0.718 | 1.440 | 1.943 | 2.104 | 2.447 | 2.612 | 3.143 | 3.707 | 4.317 | 5.208 | 6.215 |
| 7 | 0.263 | 0.711 | 1.415 | 1.895 | 2.046 | 2.365 | 2.517 | 2.998 | 3.499 | 4.029 | 4.785 | 5.598 |
| 8 | 0.262 | 0.706 | 1.397 | 1.860 | 2.004 | 2.306 | 2.449 | 2.896 | 3.355 | 3.833 | 4.501 | 5.317 |
| 9 | 0.261 | 0.703 | 1.383 | 1.833 | 1.973 | 2.262 | 2.398 | 2.821 | 3.250 | 3.690 | 4.297 | 5.041 |
| 10 | 0.260 | 0.700 | 1.372 | 1.812 | 1.948 | 2.228 | 2.359 | 2.764 | 3.169 | 3.581 | 4.144 | 4.879 |
| 11 | 0.260 | 0.697 | 1.363 | 1.796 | 1.928 | 2.201 | 2.328 | 2.718 | 3.106 | 3.497 | 4.025 | 4.755 |
| 12 | 0.259 | 0.695 | 1.356 | 1.782 | 1.912 | 2.179 | 2.303 | 2.681 | 3.055 | 3.428 | 3.930 | 4.633 |
| 13 | 0.259 | 0.694 | 1.350 | 1.771 | 1.899 | 2.160 | 2.282 | 2.650 | 3.012 | 3.372 | 3.852 | 4.561 |
| 14 | 0.258 | 0.692 | 1.345 | 1.761 | 1.887 | 2.145 | 2.264 | 2.624 | 2.977 | 3.326 | 3.787 | 4.500 |
| 15 | 0.258 | 0.691 | 1.341 | 1.753 | 1.878 | 2.131 | 2.249 | 2.602 | 2.947 | 3.286 | 3.733 | 4.450 |
| 16 | 0.258 | 0.690 | 1.337 | 1.746 | 1.869 | 2.120 | 2.235 | 2.583 | 2.921 | 3.252 | 3.686 | 4.409 |
| 17 | 0.257 | 0.689 | 1.333 | 1.740 | 1.862 | 2.110 | 2.224 | 2.567 | 2.898 | 3.222 | 3.646 | 4.370 |
| 18 | 0.257 | 0.688 | 1.330 | 1.734 | 1.855 | 2.101 | 2.214 | 2.552 | 2.878 | 3.197 | 3.610 | 4.333 |
| 19 | 0.257 | 0.688 | 1.328 | 1.729 | 1.850 | 2.093 | 2.205 | 2.539 | 2.861 | 3.174 | 3.579 | 4.300 |
| 20 | 0.257 | 0.687 | 1.325 | 1.725 | 1.844 | 2.086 | 2.197 | 2.528 | 2.845 | 3.153 | 3.552 | 4.269 |
| 21 | 0.257 | 0.686 | 1.323 | 1.721 | 1.840 | 2.080 | 2.189 | 2.518 | 2.831 | 3.135 | 3.527 | 4.240 |
| 22 | 0.256 | 0.686 | 1.321 | 1.717 | 1.835 | 2.074 | 2.183 | 2.508 | 2.819 | 3.119 | 3.505 | 4.212 |
| 23 | 0.256 | 0.685 | 1.319 | 1.714 | 1.832 | 2.069 | 2.177 | 2.500 | 2.807 | 3.104 | 3.485 | 4.185 |
| 24 | 0.256 | 0.685 | 1.318 | 1.711 | 1.828 | 2.064 | 2.172 | 2.492 | 2.797 | 3.091 | 3.467 | 4.159 |
| 25 | 0.256 | 0.684 | 1.316 | 1.708 | 1.825 | 2.060 | 2.167 | 2.485 | 2.787 | 3.078 | 3.450 | 4.133 |
| 26 | 0.256 | 0.684 | 1.315 | 1.706 | 1.822 | 2.056 | 2.162 | 2.479 | 2.779 | 3.067 | 3.435 | 4.108 |
| 27 | 0.256 | 0.684 | 1.314 | 1.703 | 1.819 | 2.052 | 2.158 | 2.473 | 2.771 | 3.057 | 3.421 | 4.083 |
| 28 | 0.256 | 0.683 | 1.313 | 1.701 | 1.817 | 2.048 | 2.154 | 2.467 | 2.763 | 3.047 | 3.408 | 4.059 |
| 29 | 0.256 | 0.683 | 1.311 | 1.699 | 1.814 | 2.045 | 2.150 | 2.462 | 2.756 | 3.038 | 3.396 | 4.035 |
| 30 | 0.256 | 0.683 | 1.310 | 1.697 | 1.812 | 2.042 | 2.147 | 2.457 | 2.750 | 3.030 | 3.385 | 4.012 |
| 31 | 0.256 | 0.682 | 1.309 | 1.696 | 1.810 | 2.040 | 2.144 | 2.453 | 2.744 | 3.022 | 3.375 | 3.989 |
| 32 | 0.255 | 0.682 | 1.309 | 1.694 | 1.808 | 2.037 | 2.141 | 2.449 | 2.738 | 3.015 | 3.365 | 3.966 |
| 33 | 0.255 | 0.682 | 1.308 | 1.692 | 1.806 | 2.035 | 2.138 | 2.445 | 2.733 | 3.008 | 3.356 | 3.943 |
| 34 | 0.255 | 0.682 | 1.307 | 1.691 | 1.805 | 2.032 | 2.136 | 2.441 | 2.728 | 3.002 | 3.348 | 3.920 |
| 35 | 0.255 | 0.682 | 1.306 | 1.690 | 1.803 | 2.030 | 2.133 | 2.438 | 2.724 | 2.996 | 3.340 | 3.897 |
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| 180 | 0.254 | 0.676 | 1.286 | 1.653 | 1.761 | 1.973 | 2.069 | 2.347 | 2.603 | 2.842 | 3.136 | 3.481 |
| 200 | 0.254 | 0.676 | 1.286 | 1.653 | 1.760 | 1.972 | 2.067 | 2.345 | 2.601 | 2.838 | 3.131 | 3.455 |
| 250 | 0.254 | 0.675 | 1.285 | 1.651 | 1.758 | 1.969 | 2.065 | 2.341 | 2.596 | 2.832 | 3.123 | 3.429 |
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T-test

- P-value: statistical significance
- We accept alternative hypothesis with a probability of $p=0.000003961$ to be wrongly accepted

T-test

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- We accept alternative hypothesis with a probability of $p=0.000003961$ to be wrongly accepted
- We consider $p<0.05$ (5%) as statistically significant
- That's a convention, there is no real reason for why that's better than $p<0.04$ or 0.06

T-test – hypothesis testing

- H_0 = true mean is equal to 18.5
- H_1 = true mean is not equal to 18.5
- `d1<-subset(d, d$YEAR==2001)`
- `t.test(d1$Tarsus, mu=18.5, na.rm=TRUE)`

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One Sample t-test

```
data: d1$Tarsus
t = -4.7719, df = 167, p-value = 3.961e-06
alternative hypothesis: true mean is not equal to 18.5
95 percent confidence interval:
 18.05779 18.31662
sample estimates:
mean of x
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```
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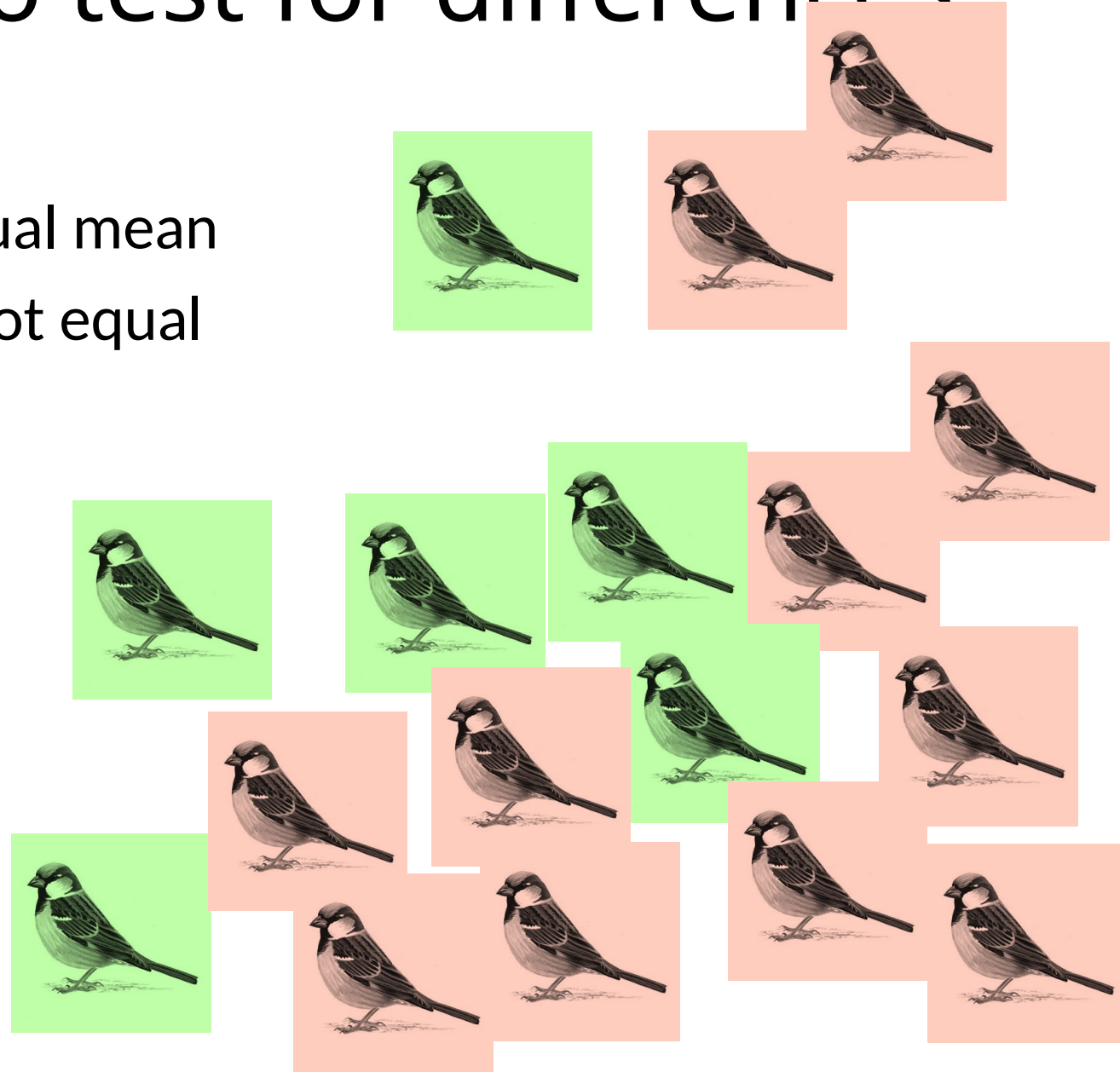
18.1872

```
> |
```

| | Tarsus | Tarsus 2001 |
|-------------------------|------------------------|---------------|
| N | 1685 | 168 |
| Standard error | | 0.07 |
| Mean | 18.52 | 18.19 |
| ~95%CI Mean+- (2*SE) | DOES NOT SPAN 18.52 | 18.05 – 18.33 |

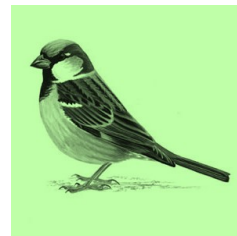
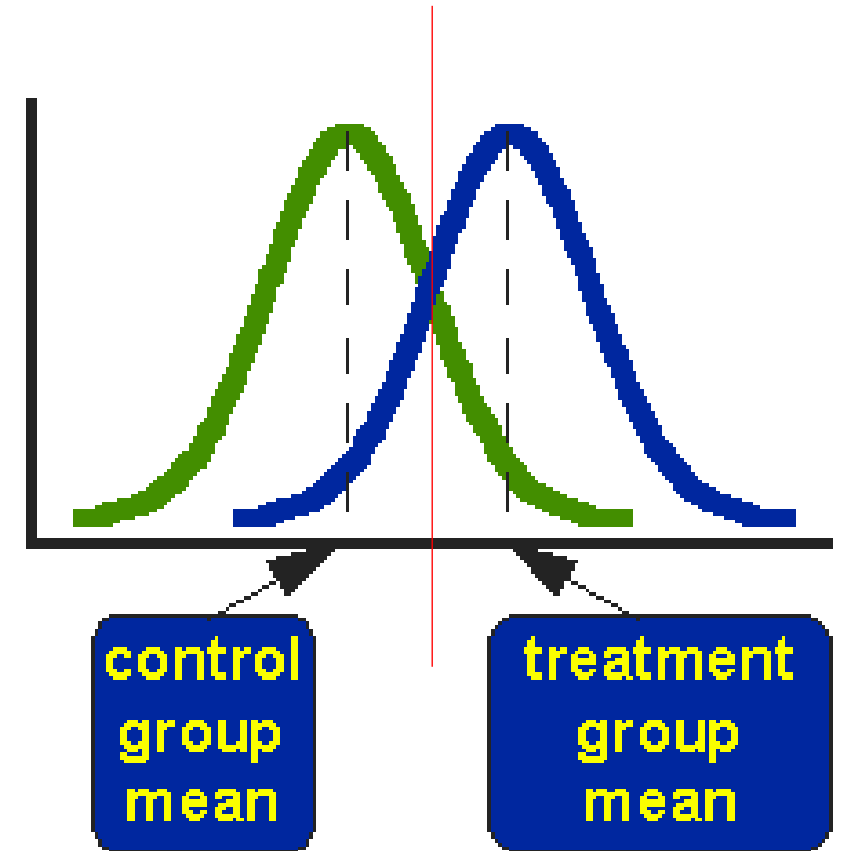
We can also use t to test for differences in mean:

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We can also use t to test for differences in mean:

- H_0 = males and females have equal mean
- H_1 = male and female mean is not equal
- \Rightarrow testing if the *difference* is
- equal to testing for zero



We can also use t to test for differences in mean:

- H_0 = males and females have equal mean
- H_1 = male and female mean is not equal

```
> t.test(d1$tarsus~d1$Sex,na.rm=TRUE)
```

Welch Two Sample t-test

```
data: d1$tarsus by d1$Sex
```

```
t = 1.2257, df = 139.07, p-value = 0.2224
```

```
alternative hypothesis: true difference in means is not equal to 0
```

```
95 percent confidence interval:
```

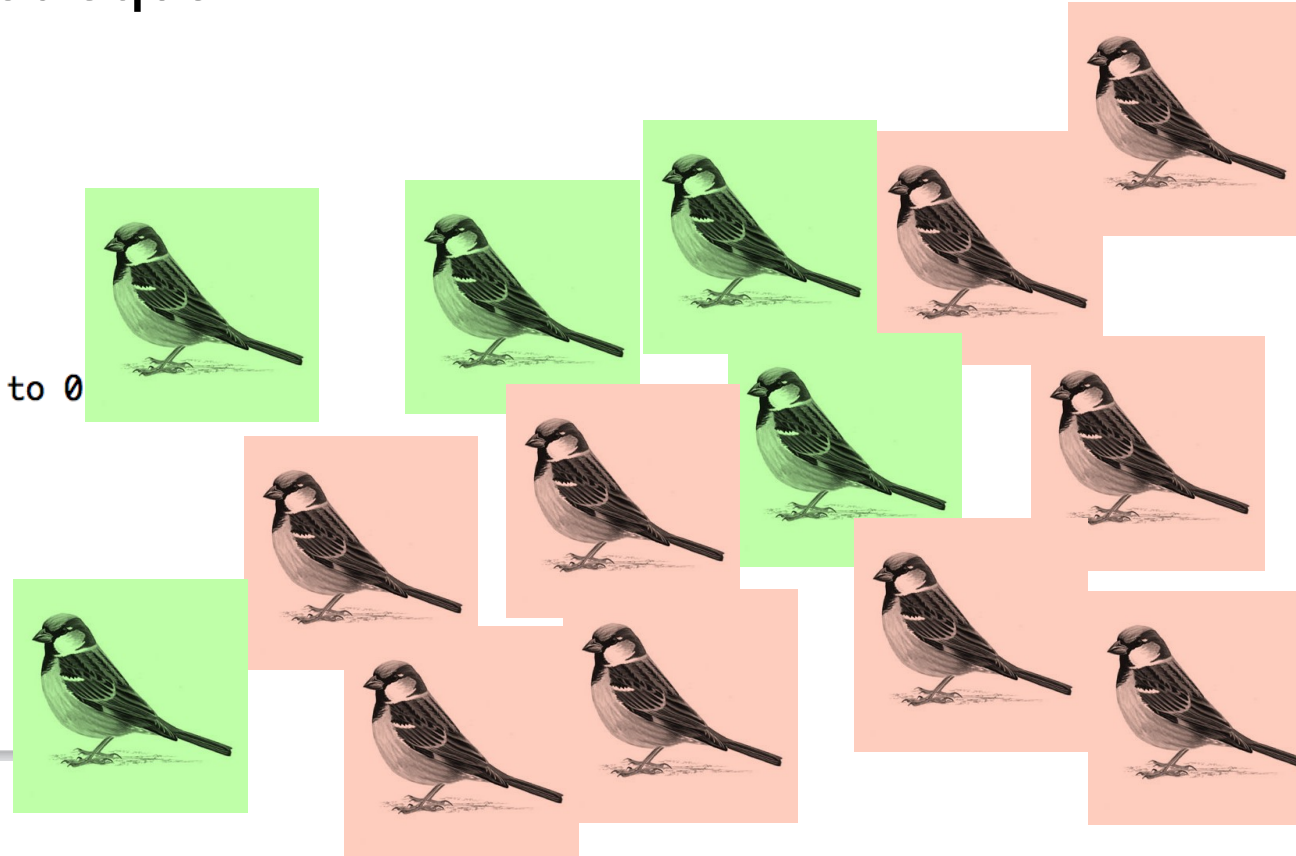
```
-0.1012318  0.4314949
```

```
sample estimates:
```

```
mean in group 0 mean in group 1
```

```
18.27763      18.11250
```

```
> |
```



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```
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```

Welch Two Sample t-test

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t = 1.2257, df = 139.07, p-value = 0.2224

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

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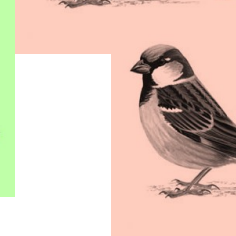
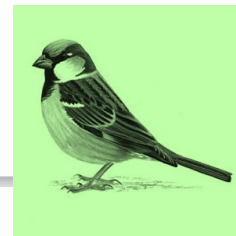
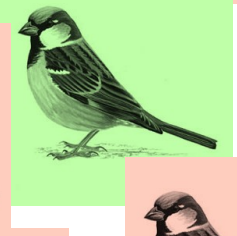
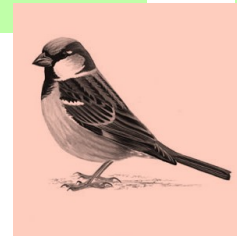
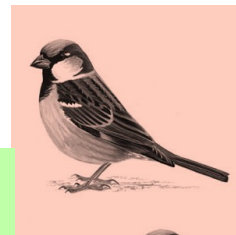
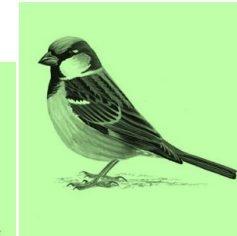
sample estimates:

mean in group 0 mean in group 1

18.27763

18.11250

```
> |
```



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- H_1 = male and female mean is not equal

```
> t.test(d1$Tarsus~d1$Sex,na.rm=TRUE)
```

Welch Two Sample t-test

```
data: d1$Tarsus by d1$Sex
```

```
t = 1.2257, df = 139.07, p-value = 0.2224
```

```
alternative hypothesis: true difference in means is not equal to 0
```

```
95 percent confidence interval:
```

```
-0.1012318  0.4314949
```

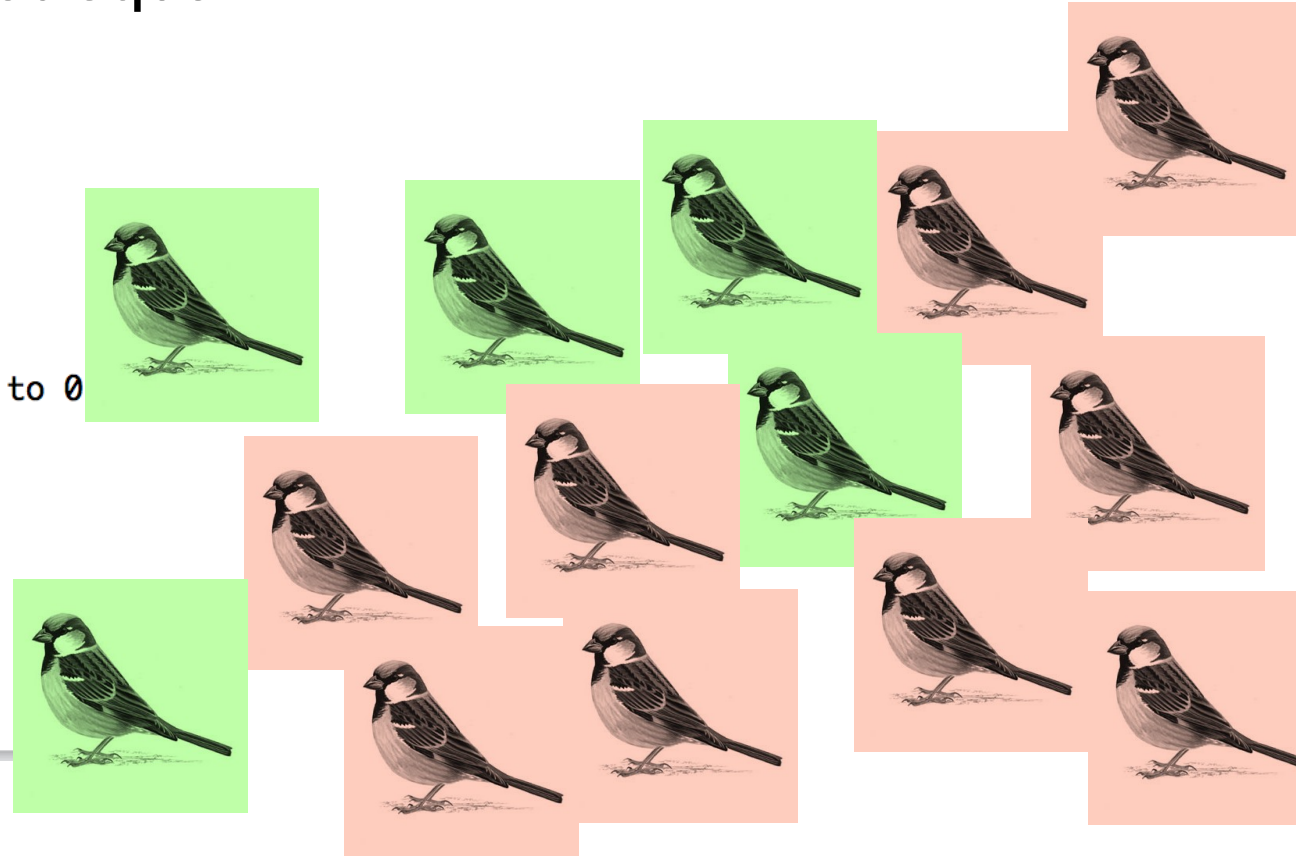
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```

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Welch Two Sample t-test

data: d1\$Tarsus by d1\$Sex

t = 1.2257, df = 139.07, p-value = 0.2224

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

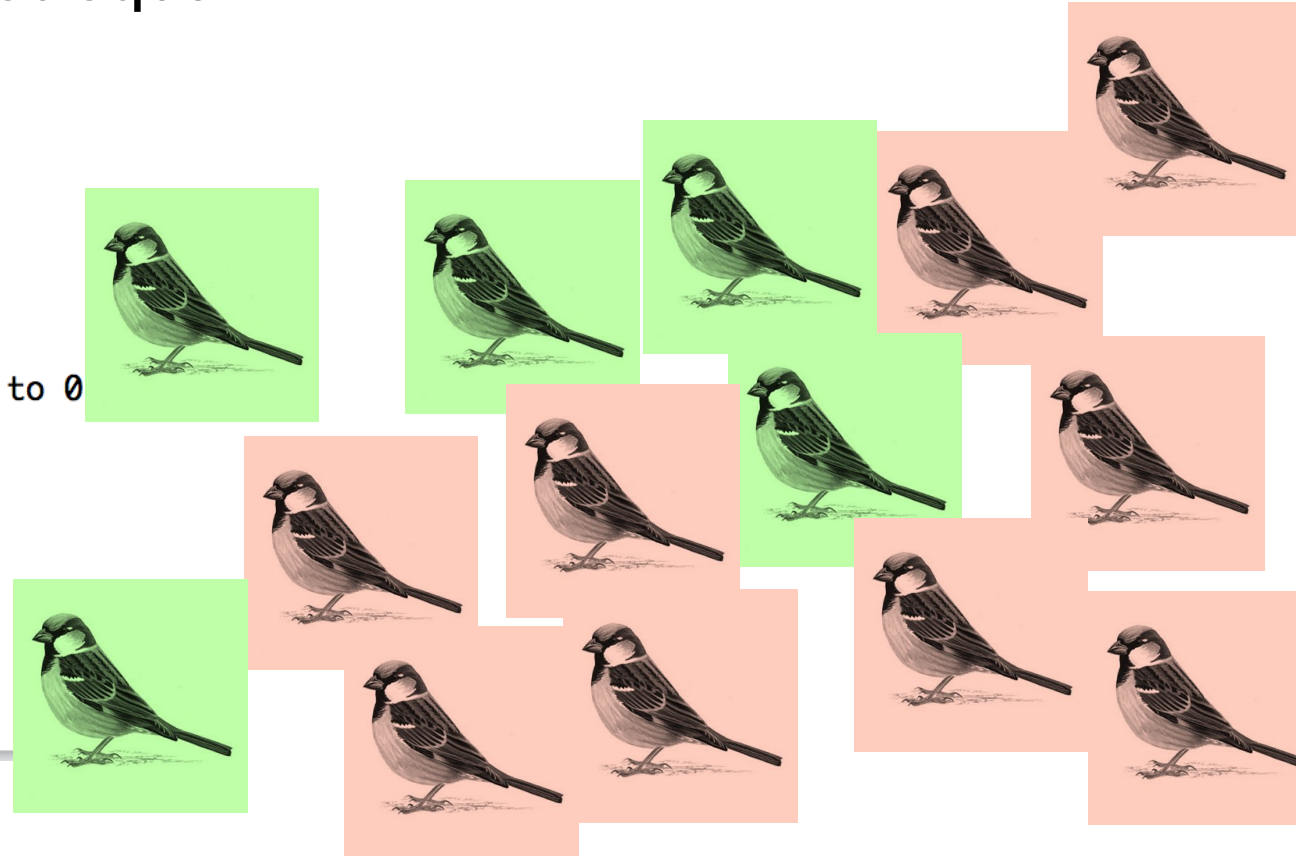
-0.1012318 0.4314949

sample estimates:

mean in group 0 mean in group 1

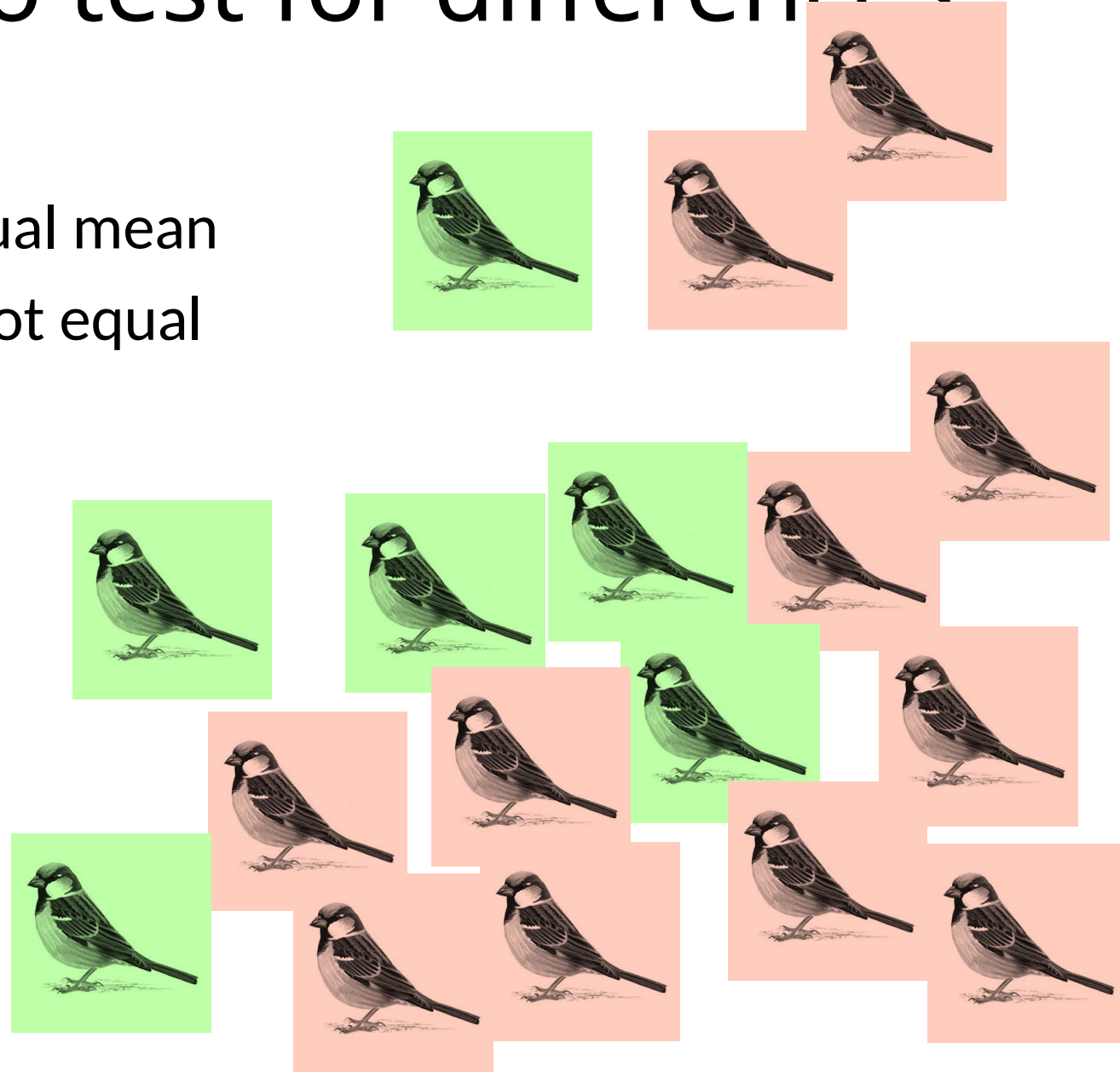
18.27763 18.11250

```
> |
```



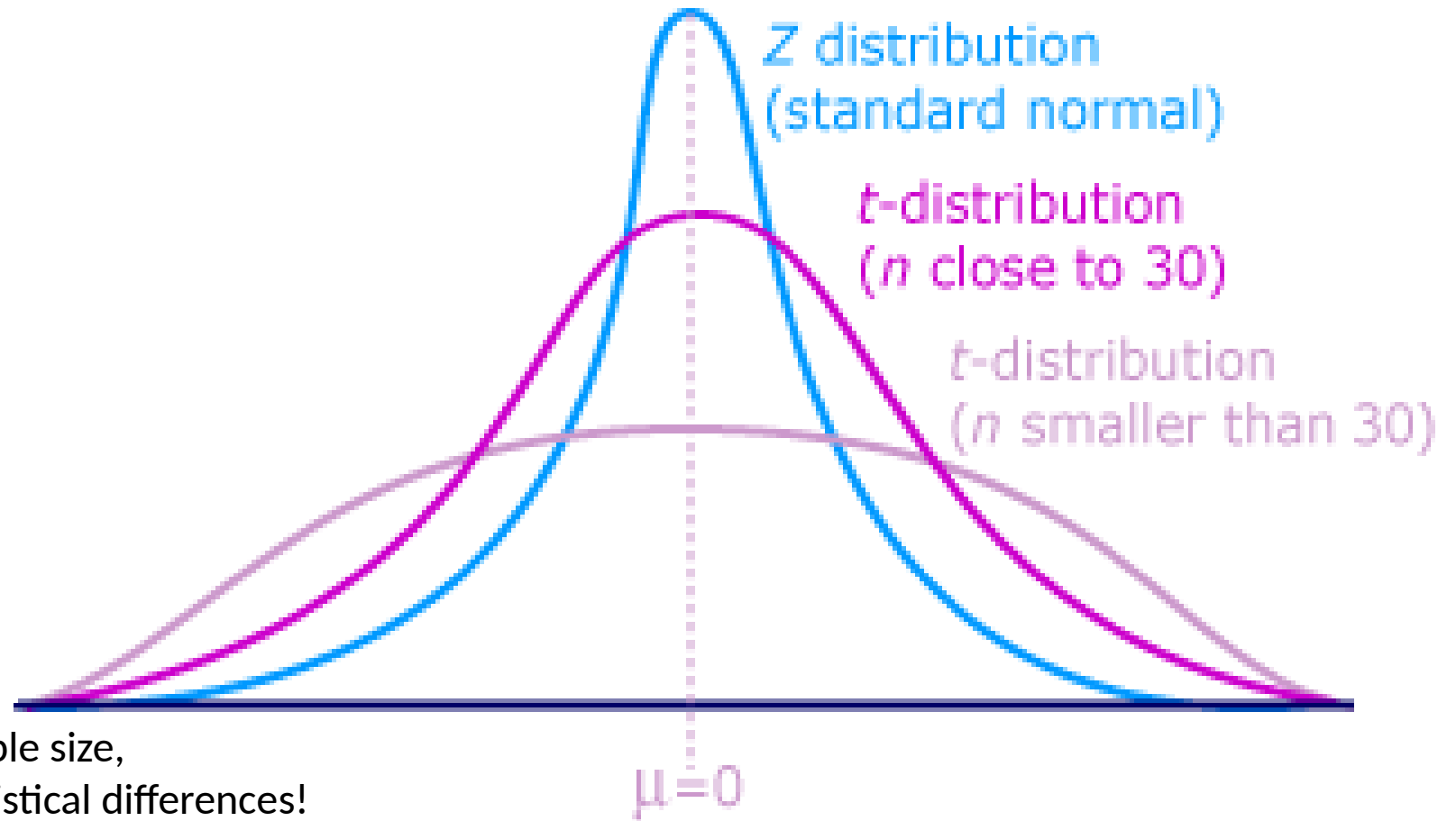
We can also use t to test for differences in mean:

- H_0 = males and females have equal mean
- H_1 = male and female mean is not equal
- \Rightarrow testing if the *difference* is
- equal to testing for zero



t-distribution: dependent on degrees of freedom

$$t_{\hat{\beta}} = \frac{\hat{\beta} - \beta_0}{\text{s. e.}(\hat{\beta})}$$



Means that the bigger the sample size,
the more likely we will find statistical differences!

Convention – reality check

- How to report results from a t-test?

```
> t.test(d1$Tarsus~d1$Sex,na.rm=TRUE)
```

Welch Two Sample t-test

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95 percent confidence interval:

-0.1012318 0.4314949

sample estimates:

mean in group 0 mean in group 1

18.27763 18.11250

```
> |
```

Convention – reality check

- How to report results from a t-test?
- In text:

Male and female tarsi did not differ in size between male and females (mean: 18.18, two sample t-test: $t=1.23$, $df=139$, $p<0.22$).

($t_{df=139}=1.23$, $p<0.001$).

```
> t.test(d1$Tarsus~d1$Sex,na.rm=TRUE)
```

Welch Two Sample t-test

```
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t = 1.2257, df = 139.07, p-value = 0.2224
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.1012318  0.4314949
sample estimates:
mean in group 0 mean in group 1
    18.27763      18.11250
```

```
> |
```

Convention – reality check

- How to report results from a t-test?
- In text:

Male and female tarsi did not differ in size
(mean: 18.18, two sample t-test: $t=1.23$, $df=139$, $p=0.22$).

($t_{df=139}=4.23$, $p<0.001$).

- In a table

| Variable | Mean females \pm SE | N females | Mean males \pm SE | N males | t | df | p |
|----------|--------------------------|--------------|------------------------|------------|------|-----|------|
| Tarsus | 18.27 \pm 0.09 | | 18.11 \pm 0.13 | | 1.23 | 139 | 0.22 |
| Wing | | | | | | | |
| Ect | | | | | | | |

```
> t.test(d1$Tarsus~d1$Sex,na.rm=TRUE)
```

Welch Two Sample t-test

```
data: d1$Tarsus by d1$Sex
t = 1.2257, df = 139.07, p-value = 0.2224
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.1012318  0.4314949
sample estimates:
mean in group 0 mean in group 1
    18.27763      18.11250
```

```
> |
```

DO IT NOW– HO 5

- Test if wing length in 2001 differs from the grand-total mean in wing length
 - Test if male and female wing length differ in 2001
 - Test if male and female wing length differ in the full dataset
 - Report in a table, don't forget the N's!
-
- Report in text

Exercise – discussion

- What did you notice happened when you took smaller samples?
- Why did the precision go down?
- How many sparrows do you have to sample to get the correct answer?