
MODULE 18

1-SAMPLE T-TEST

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PRIOR TO THIS MODULE, hypothesis testing methods required knowing σ , which is a parameter that is seldom known. When σ is replaced by its estimator, s , the test statistic follows a Student's t rather than a standard normal (Z) distribution. In this module, the t -distribution is described and a 1-Sample t -Test for testing that the mean from one population equals a specific value is discussed.

18.1 t-distribution

A t -distribution is similar to a standard normal distribution (i.e., $N(0,1)$) in that it is centered on 0 and is bell shaped (Figure 18.1). The t -distribution differs from the standard normal distribution in that it is heavier in the tails, flatter near the center, and its exact dispersion is dictated by a quantity called the degrees-of-freedom (df). The t -distribution is “flatter and fatter” because of the uncertainty surrounding the use of s rather than σ in the standard error calculation.¹ The degrees-of-freedom are related to n and generally come from the denominator in the standard deviation calculation. As the degrees-of-freedom increase, the t -distribution becomes narrower, taller, and approaches the standard normal distribution (Figure 18.1).

¹Recall that the sample standard deviation is a statistic and is thus subject to sampling variability.

Figure 18.1. Standard normal (black) and t-distributions (red) with varying degrees-of-freedom.

Proportional areas on a t-distribution are computed using `distrib()` similar to what was described for a normal distribution in Modules 8 and 12. The major exceptions for using `distrib()` with a t-distribution is that `distrib="t"` must be used and the degrees-of-freedom must be given in `df=` (how to find `df` is discussed in subsequent sections). For example, the area right of $t = -1.456$ on a t-distribution with 9 df is 0.9103 (Figure 18.2).

```
> ( distrib(-1.456,distrib="t",df=9,lower.tail=FALSE) )  
[1] 0.9103137
```

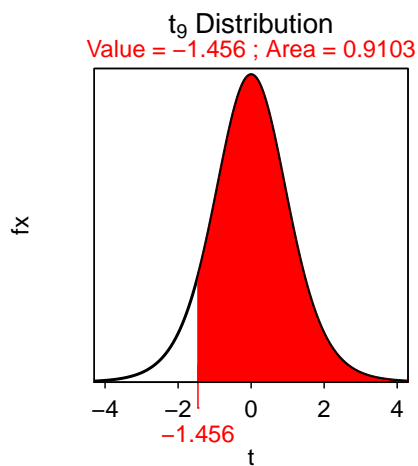


Figure 18.2. Depiction of the area to the right of $t = -1.456$ on a t-distribution with 9 df.

Similarly, the t with an upper-tail area of 0.95 on a t -distribution with 19 df is -1.729 (Figure 18.3).²

```
> ( distrib(0.95,distrib="t",type="q",df=19,lower.tail=FALSE) )
[1] -1.729133
```

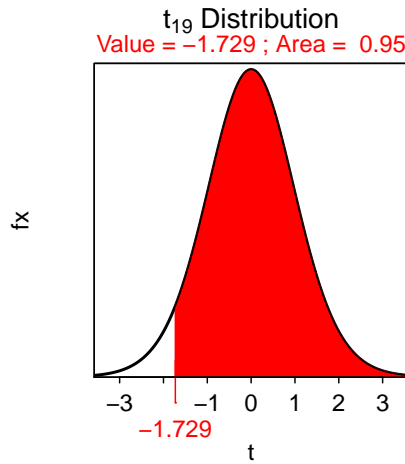


Figure 18.3. Depiction of the value of t with an area to the right of 0.95 on a t -distribution with 19 df.

18.2 1-Sample t-Test Specifics

A 1-Sample t -Test is similar to a 1-Sample Z -test in that both test the same H_0 . The difference, as discussed above, is that when σ is replaced by s , the test statistic becomes t and the scaling factor for confidence regions becomes a t^* . Other aspects are similar between the two tests as shown in Table 18.1.³

Table 18.1. Characteristics of a 1-Sample t -Test.

- **Hypothesis:** $H_0 : \mu = \mu_0$
- **Statistic:** \bar{x}
- **Test Statistic:** $t = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$
- **Confidence Region:** $\bar{x} \pm t^* \frac{s}{\sqrt{n}}$
- **df:** $n - 1$
- **Assumptions:**
 1. σ is UNKNOWN
 2. $n \geq 40$, $n \geq 15$ and the **sample** (i.e., histogram) is not strongly skewed, OR the **sample** is normally distributed.
- **Use with:** Quantitative response, one group (or population), σ UNKNOWN.

²This “reverse” calculation would be t^* for a 95% lower confidence bound.

³Compare Table 18.1 to Table 17.1.

18.2.1 Example - Purchase Catch of Salmon?

Below are the 11-steps (Section 17.1) for completing a full hypothesis test for the following situation:

A prospective buyer will buy a catch of several thousand salmon if the mean weight of all salmon in the catch is at least 19.9 lbs. A random selection of 50 salmon had a mean of 20.1 and a standard deviation of 0.76 lbs. Should the buyer accept the catch at the 5% level?

1. $\alpha=0.05$.
2. $H_0 : \mu = 19.9$ lbs vs. $H_A : \mu > 19.9$ lbs where μ is the mean weight of ALL salmon in the catch.
3. A 1-Sample t-Test is required because (i) a quantitative variable (weight) was measured, (ii) individuals from one group (or population) were considered (this catch of salmon), and (iii) σ is **UN**known.⁴
4. The data appear to be part of an observational study with random selection.
5. (i) $n=50 \geq 40$ and (ii) σ is unknown.
6. $\bar{x} = 20.1$ lbs (and $s = 0.76$ lbs).
7. $t = \frac{20.1-19.9}{\frac{0.76}{\sqrt{50}}} = \frac{0.2}{0.107} = 1.87$ with $df = 50-1 = 49$.
8. p-value = 0.0337.
9. H_0 is rejected because the p-value $< \alpha$.
10. The average weight of ALL salmon in this catch appears to be greater than 19.9 lbs; thus, the buyer should accept this catch of salmon.
11. I am 95% confident that the mean weight of ALL salmon in the catch is greater than 19.92 lbs (i.e., $20.1 - 1.677 \frac{0.76}{\sqrt{50}} = 20.1 - 0.18 = 19.92$).

R Appendix:

```
( pval <- distrib(1.87,distrib="t",df=49,lower.tail=FALSE) )
( tstar <- distrib(0.95,distrib="t",type="q",df=49,lower.tail=FALSE) )
```

18.3 1-Sample t-Test in R

If raw data exist, the calculations for a 1-Sample t-test can be efficiently computed with `t.test()`. The arguments to `t.test()` are the same as those for `z.test()`, with the exception that `sd=` is not used with `t.test()`. Thus, `t.test()` requires the vector of quantitative data as the first argument, the null hypothesized value for μ in `mu=`, the type of alternative hypothesis in `alt=` (again, can be `alt="two.sided"` (the default), `alt="less"`, or `alt="greater"`), and the level of confidence as a proportion in `conf.level=` (defaults to 0.95). The use of `t.test()` is illustrated in the following example.

18.3.1 Example - Crab Body Temperature

Below are the 11-steps (Section 17.1) for completing a full hypothesis test for the following situation:

A marine biologist wants to determine if the body temperature of crabs exposed to ambient air temperature is different than the ambient air temperature. The biologist exposed a sample of 25 crabs to an air temperature of 24.3°C for several minutes and then measured the body temperature of each crab (shown below). Test the biologist's question at the 5% level.

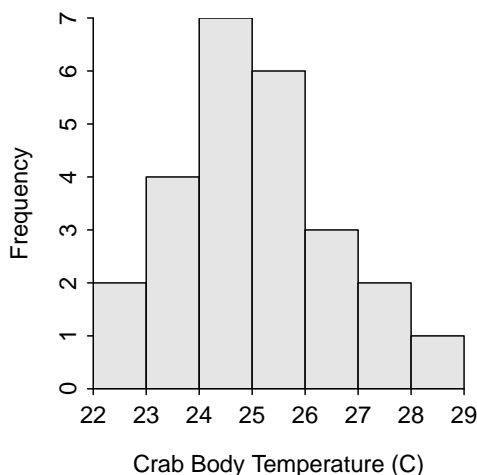
22.9, 22.9, 23.3, 23.5, 23.9, 23.9, 24.0, 24.3, 24.5, 24.6, 24.6, 24.8, 24.8,
25.1, 25.4, 25.4, 25.5, 25.5, 25.8, 26.1, 26.2, 26.3, 27.0, 27.3, 28.1

⁴If σ is given, then it will appear in the background information to the question and will be in a sentence that uses the words "population", "assume that", or "suppose that."

1. $\alpha = 0.05$.
2. $H_0 : \mu = 24.3^\circ\text{C}$ vs. $H_A : \mu \neq 24.3^\circ\text{C}$, where μ is the mean body temperature of ALL crabs.
3. A 1-Sample t-Test is required because (1) a quantitative variable (temperature) was measured, (ii) individuals from one group (or population) were considered (an ill-defined population of crabs), and (iii) σ is UNknown.
4. The data appear to be part of an experimental study (the temperature was controlled) with no suggestion of random selection of individuals.
5. (i) $n = 25 \geq 15$ and the sample distribution of crab temperatures appears to be only slightly right-skewed (Figure 18.4) and (ii) σ is UNknown.
6. $\bar{x} = 25.0^\circ\text{C}$ (Table 18.2).
7. $t = 2.713$ with 24 df (Table 18.2).
8. p-value = 0.0121 (Table 18.2).
9. H_0 is rejected because the p-value $< \alpha$.
10. It appears that the average body temperature of ALL crabs is greater than the ambient temperature of 24.3°C .
11. I am 95% confident that the mean body temperature of ALL crabs is between 24.5°C and 25.6°C (Table 18.2).

Table 18.2. Results from 1-Sample t-Test for body temperature of crabs.

```
t = 2.7128, df = 24, p-value = 0.01215
95 percent confidence interval:
 24.47413 25.58187
sample estimates:
mean of x
 25.028
```

Figure 18.4. Histogram of the body temperatures of crabs exposed to an ambient temperature of 24.3°C .**R Appendix:**

```
df <- read.csv("data/CrabTemps.csv")
hist(~ct,data=df,xlab="Crab Body Temp (C)")
( ct.t <- t.test(df$ct,mu=24.3,conf.level=0.95) )
```