Two group intervals

Statistical Inference

Brian Caffo, Jeff Leek, Roger Peng
Johns Hopkins Bloomberg School of Public Health

Independent group t confidence intervals

- Suppose that we want to compare the mean blood pressure between two groups in a randomized trial; those who received the treatment to those who received a placebo
- We cannot use the paired t test because the groups are independent and may have different sample sizes
- We now present methods for comparing independent groups

Notation

- Let $X_1, \ldots, X_{n_x}$ be iid $N(\mu_x, \sigma^2)$
- Let $Y_1, \ldots, Y_{n_y}$ be iid $N(\mu_y, \sigma^2)$
- Let $\bar X$, $\bar Y$, S_x, S_y be the means and standard deviations
- Using the fact that linear combinations of normals are again normal, we know that $\bar Y - \bar X$ is also normal with mean $\mu_y - \mu_x$ and variance $\sigma^2 (\frac{1}{n_x} + \frac{1}{n_y})$
- The pooled variance estimator

$$S_p^2 = \{(n_x - 1) S_x^2 + (n_y - 1) S_y^2\}/(n_x + n_y - 2)$$

is a good estimator of σ^2

Note

- The pooled estimator is a mixture of the group variances, placing greater weight on whichever has a larger sample size
- If the sample sizes are the same the pooled variance estimate is the average of the group variances
- The pooled estimator is unbiased

$$
\begin{aligned}
E[S_p^2] &= \frac{(n_x - 1)E[S_x^2] + (n_y - 1)E[S_y^2]}{n_x + n_y - 2} \\
&= \frac{(n_x - 1)\sigma^2 + (n_y - 1)\sigma^2}{n_x + n_y - 2}
\end{aligned}
$$

- The pooled variance estimate is independent of $\bar{Y} - \bar{X}$ since S_x is independent of $\bar{X}$ and S_y is independent of $\bar{Y}$ and the groups are independent

Result

- The sum of two independent Chi-squared random variables is Chi-squared with degrees of freedom equal to the sum of the degrees of freedom of the summands
- Therefore

$$
\begin{aligned}
(n_x + n_y - 2)S_p^2/\sigma^2 &= (n_x - 1)S_x^2/\sigma^2 + (n_y - 1)S_y^2/\sigma^2 \\
&= \chi^2_{n_x - 1} + \chi^2_{n_y - 1} \\
&= \chi^2_{n_x + n_y - 2}
\end{aligned}
$$

Putting this all together

- The statistic

$$\frac{\frac{\bar{Y}-\bar{X}-(\mu_y-\mu_x)}{\sigma\left(\frac{1}{n_x}+\frac{1}{n_y}\right)^{1/2}}}{\sqrt{\frac{(n_x+n_y-2)S_p^2}{(n_x+n_y-2)\sigma^2}}} = \frac{\bar{Y}-\bar{X}-(\mu_y-\mu_x)}{S_p\left(\frac{1}{n_x}+\frac{1}{n_y}\right)^{1/2}}$$

  is a standard normal divided by the square root of an independent Chi-squared divided by its degrees of freedom

- Therefore this statistic follows Gosset's t distribution with $n_x + n_y - 2$ degrees of freedom
- Notice the form is (estimator - true value) / SE

Confidence interval

- Therefore a $(1-\alpha)\times 100\%$ confidence interval for $\mu_y - \mu_x$ is

$$\bar{Y} - \bar{X} \pm t_{n_x+n_y-2,1-\alpha/2}\, S_p \left(\frac{1}{n_x} + \frac{1}{n_y}\right)^{1/2}$$

- Remember this interval is assuming a constant variance across the two groups
- If there is some doubt, assume a different variance per group, which we will discuss later

Example

Based on Rosner, Fundamentals of Biostatistics

- Comparing SBP for 8 oral contraceptive users versus 21 controls
- $\bar{X}_{OC} = 132.86$ mmHg with $s_{OC} = 15.34$ mmHg
- $\bar{X}_{C} = 127.44$ mmHg with $s_{C} = 18.23$ mmHg
- Pooled variance estimate

```
sp <- sqrt((7 * 15.34^2 + 20 * 18.23^2)/(8 + 21 - 2))
132.86 - 127.44 + c(-1, 1) * qt(0.975, 27) * sp * (1/8 + 1/21)^0.5
```

```
## [1] -9.521 20.361
```

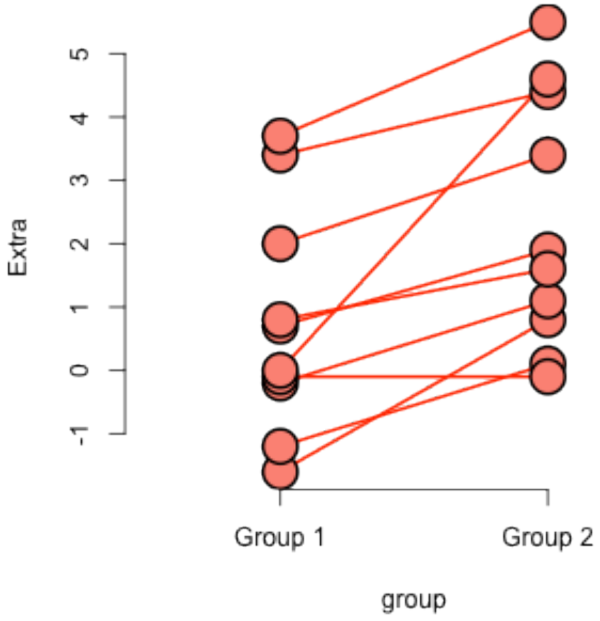
```r
data(sleep)
x1 <- sleep$extra[sleep$group == 1]
x2 <- sleep$extra[sleep$group == 2]
n1 <- length(x1)
n2 <- length(x2)
sp <- sqrt(((n1 - 1) * sd(x1)^2 + (n2 - 1) * sd(x2)^2)/(n1 + n2 - 2))
md <- mean(x1) - mean(x2)
semd <- sp * sqrt(1/n1 + 1/n2)
md + c(-1, 1) * qt(0.975, n1 + n2 - 2) * semd
```

```
## [1] -3.3639  0.2039
```

```r
t.test(x1, x2, paired = FALSE, var.equal = TRUE)$conf
```

```
## [1] -3.3639  0.2039
## attr(,"conf.level")
## [1] 0.95
```

Ignoring pairing



Unequal variances

- Under unequal variances

$$\bar{Y} - \bar{X} \sim N\left(\mu_y - \mu_x, \frac{s_x^2}{n_x} + \frac{\sigma_y^2}{n_y}\right)$$

- The statistic

$$\frac{\bar{Y} - \bar{X} - (\mu_y - \mu_x)}{\left(\frac{s_x^2}{n_x} + \frac{\sigma_y^2}{n_y}\right)^{1/2}}$$

approximately follows Gosset's t distribution with degrees of freedom equal to

$$\frac{\left(S_x^2/n_x + S_y^2/n_y\right)^2}{\left(\frac{S_x^2}{n_x}\right)^2/(n_x - 1) + \left(\frac{S_y^2}{n_y}\right)^2/(n_y - 1)}$$

Example

- Comparing SBP for 8 oral contraceptive users versus 21 controls
- $\bar{X}_{OC} = 132.86$ mmHg with $s_{OC} = 15.34$ mmHg
- $\bar{X}_{C} = 127.44$ mmHg with $s_{C} = 18.23$ mmHg
- $df = 15.04$, $t_{15.04,.975} = 2.13$
- Interval

$$132.86 - 127.44 \pm 2.13 \left(\frac{15.34^2}{8} + \frac{18.23^2}{21} \right)^{1/2} = [-8.91, 19.75]$$

- In R, `t.test(..., var.equal = FALSE)`

Comparing other kinds of data

- For binomial data, there's lots of ways to compare two groups
  - Relative risk, risk difference, odds ratio.
  - Chi-squared tests, normal approximations, exact tests.
- For count data, there's also Chi-squared tests and exact tests.
- We'll leave the discussions for comparing groups of data for binary and count data until covering glms in the regression class.
- In addition, Mathematical Biostatistics Boot Camp 2 covers many special cases relevant to biostatistics.