



ADVANCED PHARMACEUTICAL BIOSTATISTICS

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Lect 3



Example: Effect of exercise on heart rate?



- Practice: Unpaired T test
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| Subject # | Female Heights (cm) | Male Heights (cm) | D= Difference |
|-----------|---------------------|-------------------|---------------|
| 1 | 171.1 | 180.4 | -15 |
| 2 | 161.0 | 168.4 | -7 |
| 3 | 155.3 | 170.9 | -11 |
| 4 | 167.9 | 174.1 | -13 |
| 5 | 163.8 | 170.4 | -15 |
| MEAN | 163.82 | 172.84 | -9.02 |
| SD | 6.128 | 4.695 | 3.867 |

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$
$$= \frac{-9.02}{\sqrt{(6.13^2/5) + (4.69^2/5)}}$$

$$t = -2.61$$

$$t_{\text{crit}} = 2.306 \text{ (Df=8)}$$



t Table

| cum. prob | $t_{.50}$ | $t_{.75}$ | $t_{.80}$ | $t_{.85}$ | $t_{.90}$ | $t_{.95}$ | $t_{.975}$ | $t_{.99}$ | $t_{.995}$ | $t_{.999}$ | $t_{.9995}$ |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|------------|-------------|
| one-tail | 0.50 | 0.25 | 0.20 | 0.15 | 0.10 | 0.05 | 0.025 | 0.01 | 0.005 | 0.001 | 0.0005 |
| two-tails | 1.00 | 0.50 | 0.40 | 0.30 | 0.20 | 0.10 | 0.05 | 0.02 | 0.01 | 0.002 | 0.001 |
| df | | | | | | | | | | | |
| 1 | 0.000 | 1.000 | 1.376 | 1.963 | 3.078 | 6.314 | 12.71 | 31.82 | 63.66 | 318.31 | 636.62 |
| 2 | 0.000 | 0.816 | 1.061 | 1.386 | 1.886 | 2.920 | 4.303 | 6.965 | 9.925 | 22.327 | 31.599 |
| 3 | 0.000 | 0.765 | 0.978 | 1.250 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 | 10.215 | 12.924 |
| 4 | 0.000 | 0.741 | 0.941 | 1.190 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 | 7.173 | 8.610 |
| 5 | 0.000 | 0.727 | 0.920 | 1.156 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 | 5.893 | 6.869 |
| 6 | 0.000 | 0.718 | 0.906 | 1.134 | 1.440 | 1.943 | 2.447 | 3.143 | 3.707 | 5.208 | 5.959 |
| 7 | 0.000 | 0.711 | 0.896 | 1.119 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 | 4.785 | 5.408 |
| 8 | 0.000 | 0.706 | 0.889 | 1.108 | 1.397 | 1.860 | 2.306 | 2.896 | 3.355 | 4.501 | 5.041 |
| 9 | 0.000 | 0.703 | 0.883 | 1.100 | 1.383 | 1.833 | 2.262 | 2.821 | 3.250 | 4.297 | 4.781 |
| 10 | 0.000 | 0.700 | 0.879 | 1.093 | 1.372 | 1.812 | 2.228 | 2.764 | 3.169 | 4.144 | 4.587 |
| 11 | 0.000 | 0.697 | 0.876 | 1.088 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 | 4.025 | 4.437 |
| 12 | 0.000 | 0.695 | 0.873 | 1.083 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 | 3.930 | 4.318 |
| 13 | 0.000 | 0.694 | 0.870 | 1.079 | 1.350 | 1.771 | 2.160 | 2.650 | 3.012 | 3.852 | 4.221 |
| 14 | 0.000 | 0.692 | 0.868 | 1.076 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 | 3.787 | 4.140 |
| 15 | 0.000 | 0.691 | 0.866 | 1.074 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 | 3.733 | 4.073 |
| 16 | 0.000 | 0.690 | 0.865 | 1.071 | 1.337 | 1.746 | 2.120 | 2.583 | 2.921 | 3.686 | 4.015 |
| 17 | 0.000 | 0.689 | 0.863 | 1.069 | 1.333 | 1.740 | 2.110 | 2.567 | 2.898 | 3.646 | 3.965 |
| 18 | 0.000 | 0.688 | 0.862 | 1.067 | 1.330 | 1.734 | 2.101 | 2.552 | 2.878 | 3.610 | 3.922 |
| 19 | 0.000 | 0.688 | 0.861 | 1.066 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 | 3.579 | 3.883 |
| 20 | 0.000 | 0.687 | 0.860 | 1.064 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 | 3.552 | 3.850 |
| 21 | 0.000 | 0.686 | 0.859 | 1.063 | 1.323 | 1.721 | 2.080 | 2.518 | 2.831 | 3.527 | 3.819 |
| 22 | 0.000 | 0.686 | 0.858 | 1.061 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 | 3.505 | 3.792 |
| 23 | 0.000 | 0.685 | 0.858 | 1.060 | 1.319 | 1.714 | 2.069 | 2.500 | 2.807 | 3.485 | 3.768 |
| 24 | 0.000 | 0.685 | 0.857 | 1.059 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 | 3.467 | 3.745 |
| 25 | 0.000 | 0.684 | 0.856 | 1.058 | 1.316 | 1.708 | 2.060 | 2.485 | 2.787 | 3.450 | 3.725 |
| 26 | 0.000 | 0.684 | 0.856 | 1.058 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 | 3.435 | 3.707 |
| 27 | 0.000 | 0.684 | 0.855 | 1.057 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 | 3.421 | 3.690 |
| 28 | 0.000 | 0.683 | 0.855 | 1.056 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 | 3.408 | 3.674 |
| 29 | 0.000 | 0.683 | 0.854 | 1.055 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 | 3.396 | 3.659 |
| 30 | 0.000 | 0.683 | 0.854 | 1.055 | 1.310 | 1.697 | 2.042 | 2.457 | 2.750 | 3.385 | 3.646 |
| 40 | 0.000 | 0.681 | 0.851 | 1.050 | 1.303 | 1.684 | 2.021 | 2.423 | 2.704 | 3.307 | 3.551 |
| 60 | 0.000 | 0.679 | 0.848 | 1.045 | 1.296 | 1.671 | 2.000 | 2.390 | 2.660 | 3.232 | 3.460 |
| 80 | 0.000 | 0.678 | 0.846 | 1.043 | 1.292 | 1.664 | 1.990 | 2.374 | 2.639 | 3.195 | 3.416 |
| 100 | 0.000 | 0.677 | 0.845 | 1.042 | 1.290 | 1.660 | 1.984 | 2.364 | 2.626 | 3.174 | 3.390 |
| 1000 | 0.000 | 0.675 | 0.842 | 1.037 | 1.282 | 1.646 | 1.962 | 2.330 | 2.581 | 3.098 | 3.300 |
| Z | 0.000 | 0.674 | 0.842 | 1.036 | 1.282 | 1.645 | 1.960 | 2.326 | 2.576 | 3.090 | 3.291 |
| | 0% | 50% | 60% | 70% | 80% | 90% | 95% | 98% | 99% | 99.8% | 99.9% |



Example: Effect of exercise on heart rate?



- Practice: paired T test
-

| Subject # | Heart Rate (Resting) Beats/min | Heart Rate (After Exercise) Beats/min | D= Difference |
|-----------|--------------------------------|---------------------------------------|---------------|
| 1 | 70 | 85 | -15.0 |
| 2 | 74 | 81 | -7.0 |
| 3 | 68 | 79 | -11.0 |
| 4 | 55 | 68 | -13.0 |
| 5 | 80 | 95 | -15.0 |
| MEAN | 69.4 | 81.6 | -12.2 |
| SE | 4.14 | 4.38 | 1.50 |

$$t = \frac{\bar{D}}{SE_D}$$

$$t = \frac{-12.2}{1.5}$$

$$t = -8.15$$

$$t_{crit} = 2.776 (Df=4)$$



Example: Effect of exercise on heart rate?



- Practice: one sample T test
-

| Subject # | Human IQ | Average normal | D= Difference |
|-----------|----------|----------------|---------------|
| 1 | 85 | 100 | |
| 2 | 120 | | |
| 3 | 90 | | |
| 4 | 105 | | |
| 5 | 110 | | |
| MEAN | 135 | | 35.7 |
| SE | 6.37 | | |

$$t = \frac{\bar{X} - M}{SE_1}$$

$$t = \frac{35.7}{6.37}$$

$$t = 5.61$$

$$t \text{ crit} = 1.833 \text{ (Df=9)}$$



ANOVA



Analysis of Variance

Family of hypothesis tests for comparing multiple (3+) sample groups.

ANOVA tests compare the means of one or more **dependent** variables, measured from groups of subjects categorised according to one or more **independent variables (factors)**, representing different treatments or properties of the within each group.



ANOVA Terminology



Dependent Variable (or response)

The measured experimental variable of interest which are affected by the factors.

e.g. weight, blood pressure, heart rate.

Factor (or independent variable)

Variable (usually nominal) representing the factors that affect the dependent variable

e.g. gender, treatment

Levels (of the factor)

Individual values of the factor variable representing the treatment or property used to categorise the subjects into groups.

e.g. The gender factor would have 2 levels: Male & Female.



Common Types of Analysis of Variance

One way ANOVA

Single factor, multiple levels.

Compares differences between means of 3 or more independent groups of subjects

One way (repeated measures) ANOVA

Single factor, multiple levels

Compares differences between means of 3 or more groups of measurements repeatedly made on the same subjects

Two way ANOVA

Two factors, multiple levels.

Determines whether each of the two factors have an effect on the dependent variable and whether there is interaction between the factors.
May be independent subjects, repeated measures or mixed.



One way ANOVA



Four gps of patients were subjected to 4 different physical treatments therapy abd at end the following scores were obtained . Analysis the treatment effectiveness

| | TR A | TR B | TR C | TR D | |
|------|------|------|------|------|------|
| | 64 | 76 | 58 | 95 | |
| | 88 | 70 | 74 | 90 | |
| | 72 | 90 | 66 | 80 | |
| | 80 | 80 | 60 | 87 | |
| | 79 | 75 | 82 | 88 | |
| | 71 | 82 | 75 | 85 | |
| Sum | 454 | 473 | 415 | 525 | 1867 |
| Mean | 75.7 | 78.8 | 69.2 | 87.5 | |

1- Ground total =1867

2- Mean of All $\bar{x} = 1867/24= 77.9$

3- Corr. Factor $= \frac{(\sum(\sum x))^2}{24} = 145237.04$

4-Total SS $= (\sum(X^2)) - CF = 2201.96$

5-between Tr ss $= \frac{\sum((\sum X)^2)}{6} - CF = \frac{254^2+254^2+254^2+254^2}{6} - CF = 1045.46$

6- within tr ss = total ss – bet Tr ss = 2201.96 - 1045.46 = 1156.5

| SOURCE OF VARIANCE | D.F | SS | Ms (Mean Squire) = ss/D.F | F =ms/ms | Table 0.05 | Table 0.01 |
|--------------------|-----|---------|---------------------------|----------|------------|------------|
| Bet gps | 3 | 1045.46 | 348.5 | 6.03 | 3.1 | 4.94 |
| Withn gps | 20 | 1156.5 | 57.83 | | | |
| total | 23 | | | | | |



| DF2 | DF1 | | $\alpha = 0.05$ | | | | | | | | | | | | | | | | |
|-----|--------|--------|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 24 | 30 | 40 | 60 | 120 | Inf |
| 1 | 161.45 | 199.5 | 215.71 | 224.58 | 230.16 | 233.99 | 236.77 | 238.88 | 240.54 | 241.88 | 243.91 | 245.95 | 248.01 | 249.05 | 250.1 | 251.14 | 252.2 | 253.25 | 254.31 |
| 2 | 18.513 | 19 | 19.164 | 19.247 | 19.296 | 19.33 | 19.353 | 19.371 | 19.385 | 19.396 | 19.413 | 19.429 | 19.446 | 19.454 | 19.462 | 19.471 | 19.479 | 19.487 | 19.496 |
| 3 | 10.128 | 9.5521 | 9.2766 | 9.1172 | 9.0135 | 8.9406 | 8.8867 | 8.8452 | 8.8123 | 8.7855 | 8.7446 | 8.7029 | 8.6602 | 8.6385 | 8.6166 | 8.5944 | 8.572 | 8.5494 | 8.5264 |
| 4 | 7.7086 | 6.9443 | 6.5914 | 6.3882 | 6.2561 | 6.1631 | 6.0942 | 6.041 | 5.9988 | 5.9644 | 5.9117 | 5.8578 | 5.8025 | 5.7744 | 5.7459 | 5.717 | 5.6877 | 5.6581 | 5.6281 |
| 5 | 6.6079 | 5.7861 | 5.4095 | 5.1922 | 5.0503 | 4.9503 | 4.8759 | 4.8183 | 4.7725 | 4.7351 | 4.6777 | 4.6188 | 4.5581 | 4.5272 | 4.4957 | 4.4638 | 4.4314 | 4.3985 | 4.365 |
| 6 | 5.9874 | 5.1433 | 4.7571 | 4.5337 | 4.3874 | 4.2839 | 4.2067 | 4.1468 | 4.099 | 4.06 | 3.9999 | 3.9381 | 3.8742 | 3.8415 | 3.8082 | 3.7743 | 3.7398 | 3.7047 | 3.6689 |
| 7 | 5.5914 | 4.7374 | 4.3468 | 4.1203 | 3.9715 | 3.866 | 3.787 | 3.7257 | 3.6767 | 3.6365 | 3.5747 | 3.5107 | 3.4445 | 3.4105 | 3.3758 | 3.3404 | 3.3043 | 3.2674 | 3.2298 |
| 8 | 5.3177 | 4.459 | 4.0662 | 3.8379 | 3.6875 | 3.5806 | 3.5005 | 3.4381 | 3.3881 | 3.3472 | 3.2839 | 3.2184 | 3.1503 | 3.1152 | 3.0794 | 3.0428 | 3.0053 | 2.9669 | 2.9276 |
| 9 | 5.1174 | 4.2565 | 3.8625 | 3.6331 | 3.4817 | 3.3738 | 3.2927 | 3.2296 | 3.1789 | 3.1373 | 3.0729 | 3.0061 | 2.9365 | 2.9005 | 2.8637 | 2.8259 | 2.7872 | 2.7475 | 2.7067 |
| 10 | 4.9646 | 4.1028 | 3.7083 | 3.478 | 3.3258 | 3.2172 | 3.1355 | 3.0717 | 3.0204 | 2.9782 | 2.913 | 2.845 | 2.774 | 2.7372 | 2.6996 | 2.6609 | 2.6211 | 2.5801 | 2.5379 |
| 11 | 4.8443 | 3.9823 | 3.5874 | 3.3567 | 3.2039 | 3.0946 | 3.0123 | 2.948 | 2.8962 | 2.8536 | 2.7876 | 2.7186 | 2.6464 | 2.609 | 2.5705 | 2.5309 | 2.4901 | 2.448 | 2.4045 |
| 12 | 4.7472 | 3.8853 | 3.4903 | 3.2592 | 3.1059 | 2.9961 | 2.9134 | 2.8486 | 2.7964 | 2.7534 | 2.6866 | 2.6169 | 2.5436 | 2.5055 | 2.4663 | 2.4259 | 2.3842 | 2.341 | 2.2962 |
| 13 | 4.6672 | 3.8056 | 3.4105 | 3.1791 | 3.0254 | 2.9153 | 2.8321 | 2.7669 | 2.7144 | 2.671 | 2.6037 | 2.5331 | 2.4589 | 2.4202 | 2.3803 | 2.3392 | 2.2966 | 2.2524 | 2.2064 |
| 14 | 4.6001 | 3.7389 | 3.3439 | 3.1122 | 2.9582 | 2.8477 | 2.7642 | 2.6987 | 2.6458 | 2.6022 | 2.5342 | 2.463 | 2.3879 | 2.3487 | 2.3082 | 2.2664 | 2.2229 | 2.1778 | 2.1307 |
| 15 | 4.5431 | 3.6823 | 3.2874 | 3.0556 | 2.9013 | 2.7905 | 2.7066 | 2.6408 | 2.5876 | 2.5437 | 2.4753 | 2.4034 | 2.3275 | 2.2878 | 2.2468 | 2.2043 | 2.1601 | 2.1141 | 2.0658 |
| 16 | 4.494 | 3.6337 | 3.2389 | 3.0069 | 2.8524 | 2.7413 | 2.6572 | 2.5911 | 2.5377 | 2.4935 | 2.4247 | 2.3522 | 2.2756 | 2.2354 | 2.1938 | 2.1507 | 2.1058 | 2.0589 | 2.0096 |
| 17 | 4.4513 | 3.5915 | 3.1968 | 2.9647 | 2.81 | 2.6987 | 2.6143 | 2.548 | 2.4943 | 2.4499 | 2.3807 | 2.3077 | 2.2304 | 2.1898 | 2.1477 | 2.104 | 2.0584 | 2.0107 | 1.9604 |
| 18 | 4.4139 | 3.5546 | 3.1599 | 2.9277 | 2.7729 | 2.6613 | 2.5767 | 2.5102 | 2.4563 | 2.4117 | 2.3421 | 2.2686 | 2.1906 | 2.1497 | 2.1071 | 2.0629 | 2.0166 | 1.9681 | 1.9168 |
| 19 | 4.3807 | 3.5219 | 3.1274 | 2.8951 | 2.7401 | 2.6283 | 2.5435 | 2.4768 | 2.4227 | 2.3779 | 2.308 | 2.2341 | 2.1555 | 2.1141 | 2.0712 | 2.0264 | 1.9795 | 1.9302 | 1.878 |
| 20 | 4.3512 | 3.4928 | 3.0984 | 2.8661 | 2.7109 | 2.599 | 2.514 | 2.4471 | 2.3928 | 2.3479 | 2.2776 | 2.2033 | 2.1242 | 2.0825 | 2.0391 | 1.9938 | 1.9464 | 1.8963 | 1.8432 |
| 21 | 4.3248 | 3.4668 | 3.0725 | 2.8401 | 2.6848 | 2.5727 | 2.4876 | 2.4205 | 2.366 | 2.321 | 2.2504 | 2.1757 | 2.096 | 2.054 | 2.0102 | 1.9645 | 1.9165 | 1.8657 | 1.8117 |
| 22 | 4.3009 | 3.4434 | 3.0491 | 2.8167 | 2.6613 | 2.5491 | 2.4638 | 2.3965 | 2.3419 | 2.2967 | 2.2258 | 2.1508 | 2.0707 | 2.0283 | 1.9842 | 1.938 | 1.8894 | 1.838 | 1.7831 |
| 23 | 4.2793 | 3.4221 | 3.028 | 2.7955 | 2.64 | 2.5277 | 2.4422 | 2.3748 | 2.3201 | 2.2747 | 2.2036 | 2.1282 | 2.0476 | 2.005 | 1.9605 | 1.9139 | 1.8648 | 1.8128 | 1.757 |
| 24 | 4.2597 | 3.4028 | 3.0088 | 2.7763 | 2.6207 | 2.5082 | 2.4226 | 2.3551 | 2.3002 | 2.2547 | 2.1834 | 2.1077 | 2.0267 | 1.9838 | 1.939 | 1.892 | 1.8424 | 1.7896 | 1.733 |
| 25 | 4.2417 | 3.3852 | 2.9912 | 2.7587 | 2.603 | 2.4904 | 2.4047 | 2.3371 | 2.2821 | 2.2365 | 2.1649 | 2.0889 | 2.0075 | 1.9643 | 1.9192 | 1.8718 | 1.8217 | 1.7684 | 1.711 |
| 26 | 4.2252 | 3.369 | 2.9752 | 2.7426 | 2.5868 | 2.4741 | 2.3883 | 2.3205 | 2.2655 | 2.2197 | 2.1479 | 2.0716 | 1.9898 | 1.9464 | 1.901 | 1.8533 | 1.8027 | 1.7488 | 1.6906 |
| 27 | 4.21 | 3.3541 | 2.9604 | 2.7278 | 2.5719 | 2.4591 | 2.3732 | 2.3053 | 2.2501 | 2.2043 | 2.1323 | 2.0558 | 1.9736 | 1.9299 | 1.8842 | 1.8361 | 1.7851 | 1.7306 | 1.6717 |
| 28 | 4.196 | 3.3404 | 2.9467 | 2.7141 | 2.5581 | 2.4453 | 2.3593 | 2.2913 | 2.236 | 2.19 | 2.1179 | 2.0411 | 1.9586 | 1.9147 | 1.8687 | 1.8203 | 1.7689 | 1.7138 | 1.6541 |
| 29 | 4.183 | 3.3277 | 2.934 | 2.7014 | 2.5454 | 2.4324 | 2.3463 | 2.2783 | 2.2229 | 2.1768 | 2.1045 | 2.0275 | 1.9446 | 1.9005 | 1.8543 | 1.8055 | 1.7537 | 1.6981 | 1.6376 |
| 30 | 4.1709 | 3.3158 | 2.9223 | 2.6896 | 2.5336 | 2.4205 | 2.3343 | 2.2662 | 2.2107 | 2.1646 | 2.0921 | 2.0148 | 1.9317 | 1.8874 | 1.8409 | 1.7918 | 1.7396 | 1.6835 | 1.6223 |
| 40 | 4.0847 | 3.2317 | 2.8387 | 2.606 | 2.4495 | 2.3359 | 2.249 | 2.1802 | 2.124 | 2.0772 | 2.0035 | 1.9245 | 1.8389 | 1.7929 | 1.7444 | 1.6928 | 1.6373 | 1.5766 | 1.5089 |
| 60 | 4.0012 | 3.1504 | 2.7581 | 2.5252 | 2.3683 | 2.2541 | 2.1665 | 2.097 | 2.0401 | 1.9926 | 1.9174 | 1.8364 | 1.748 | 1.7001 | 1.6491 | 1.5943 | 1.5343 | 1.4673 | 1.3893 |
| 120 | 3.9201 | 3.0718 | 2.6802 | 2.4472 | 2.2899 | 2.175 | 2.0868 | 2.0164 | 1.9588 | 1.9105 | 1.8337 | 1.7505 | 1.6587 | 1.6084 | 1.5543 | 1.4952 | 1.429 | 1.3519 | 1.2539 |
| Inf | 3.8415 | 2.9957 | 2.6049 | 2.3719 | 2.2141 | 2.0986 | 2.0096 | 1.9384 | 1.8799 | 1.8307 | 1.7522 | 1.6664 | 1.5705 | 1.5173 | 1.4591 | 1.394 | 1.318 | 1.2214 | 1 |



Excell

| ANOVA | | | | | | |
|---------------------|----------|----|--------|------|---------|--------|
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 1045.46 | 3 | 348.5 | 6.03 | 0.004 | 3.098 |
| Within Groups | 1156.5 | 20 | 57.825 | | | |
| | | | | | | |
| Total | 2201.958 | 23 | | | | |

Minitab

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|--------|----|--------|--------|---------|---------|
| Factor | 3 | 1045 | 348.49 | 6.03 | 0.004 |
| Error | 20 | 1157 | 57.83 | | |
| Total | 23 | 2202 | | | |



Least significant difference



$$LSD_{0.05} = \sqrt{\frac{2(MS)}{n}} = \sqrt{\frac{2(57.83)}{6}} = 4.39$$

$$C.V = \sqrt{\frac{MS}{X}} \cdot 100\% = \frac{57.83}{77.8} \cdot 100\% = 9.77\%$$

| TR | Mean | relation |
|----|------|-----------------------------|
| C | 69.2 | C-A=6.4, C-B=9.7, C-D=18.3 |
| A | 75.6 | A-B=1.2, A-D=11.8, C-A=6.4 |
| B | 78.8 | B-D=8.7, B-C=9.7, B-A=1.2 |
| D | 87.5 | D-C=18.3, D-A=11.8, B-D=8.7 |

No. of comparisons for given group size

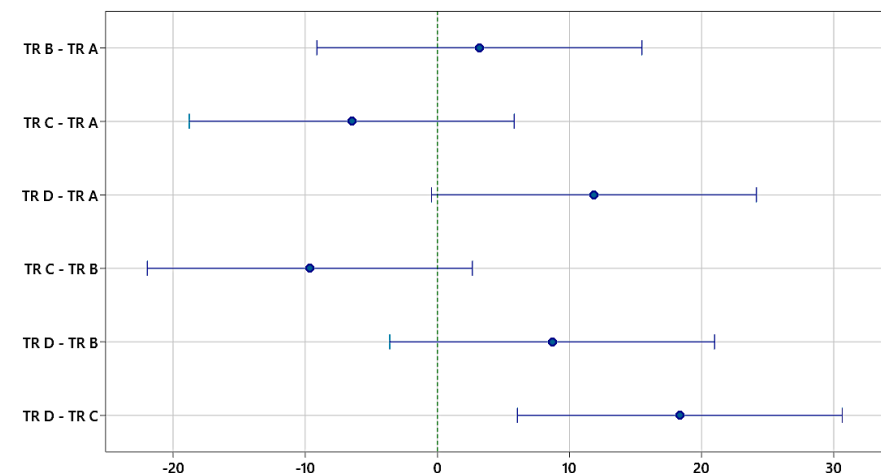
$$n_{comparisons} = \frac{n_{grps} \times (n_{grps} - 1)}{2} \quad 6 = \frac{4 \times 3}{2}$$

Tukey Simultaneous Tests for Differences of Means

| Difference of Levels | Difference of Means | SE of Difference | 95% CI | T-Value | Adjusted P-Value |
|----------------------|---------------------|------------------|----------------|---------|------------------|
| TR B - TR A | 3.17 | 4.39 | (-9.13, 15.46) | 0.72 | 0.887 |
| TR C - TR A | -6.50 | 4.39 | (-18.79, 5.79) | -1.48 | 0.467 |
| TR D - TR A | 11.83 | 4.39 | (-0.46, 24.13) | 2.70 | 0.062 |
| TR C - TR B | -9.67 | 4.39 | (-21.96, 2.63) | -2.20 | 0.157 |
| TR D - TR B | 8.67 | 4.39 | (-3.63, 20.96) | 1.97 | 0.231 |
| TR D - TR C | 18.33 | 4.39 | (6.04, 30.63) | 4.18 | 0.002 |

Individual confidence level = 98.89%

Tukey Simultaneous 95% CIs
Difference of Means for TR A, TR B, ...



If an interval does not contain zero, the corresponding means are significantly different.



Least significant difference



$$LSD_{0.05} = \sqrt{\frac{2(MS)}{n}} = \sqrt{\frac{2(57.83)}{6}} = 9.16$$

$$C.V = \sqrt{\frac{MS}{X}} \cdot 100\% = \frac{57.83}{77.8} \cdot 100\% = 9.77\%$$

| TR | Mean | relation |
|----|------|------------------------------|
| C | 69.2 | C-A=6.4, C-B=9.7, C-D=18.3 |
| A | 75.6 | A-B =1.2, A-D=11.8, C-A=6.4 |
| B | 78.8 | B-D=8.7, B-C=9.7, B-A =1.2 |
| D | 87.5 | D-C=18.3, D-A =11.8, B-D=8.7 |

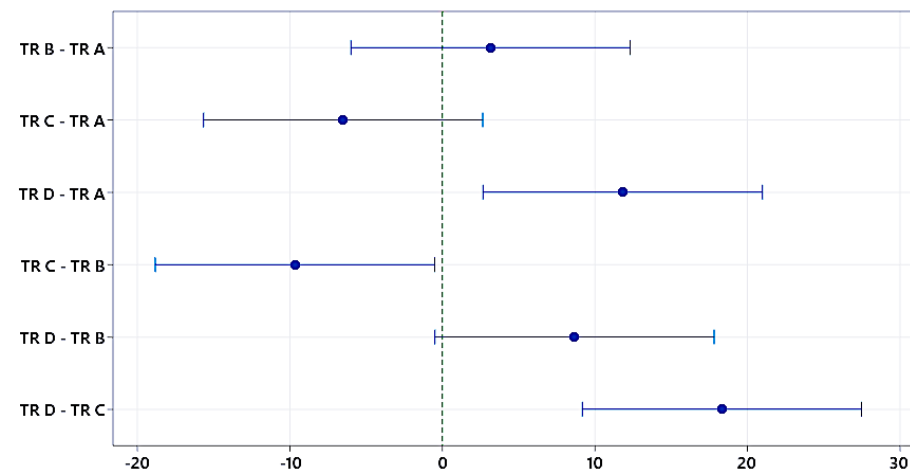
Fisher Individual Tests for Differences of Means

| Difference of Levels | Difference of Means | SE of Difference | 95% CI | T-Value | Adjusted P-Value |
|----------------------|---------------------|------------------|-----------------|---------|------------------|
| TR B - TR A | 3.17 | 4.39 | (-5.99, 12.32) | 0.72 | 0.479 |
| TR C - TR A | -6.50 | 4.39 | (-15.66, 2.66) | -1.48 | 0.154 |
| TR D - TR A | 11.83 | 4.39 | (2.68, 20.99) | 2.70 | 0.014 |
| TR C - TR B | -9.67 | 4.39 | (-18.82, -0.51) | -2.20 | 0.040 |
| TR D - TR B | 8.67 | 4.39 | (-0.49, 17.82) | 1.97 | 0.062 |
| TR D - TR C | 18.33 | 4.39 | (9.18, 27.49) | 4.18 | 0.000 |

Simultaneous confidence level = 80.83%

Fisher Individual 95% CIs

Difference of Means for TR A, TR B, ...



If an interval does not contain zero, the corresponding means are significantly different.



Example: Investigation of the effects of a diet and/or exercise program on body weight.

Test subjects split into 4 groups.

| Group Code | Treatment | No. Subjects |
|------------|---|--------------|
| C | No dieting, no exercise (control group) | 5 |
| D | Dieting, no exercise | 5 |
| E | Exercise, no dieting | 5 |
| DE | Dieting + exercise | 5 |

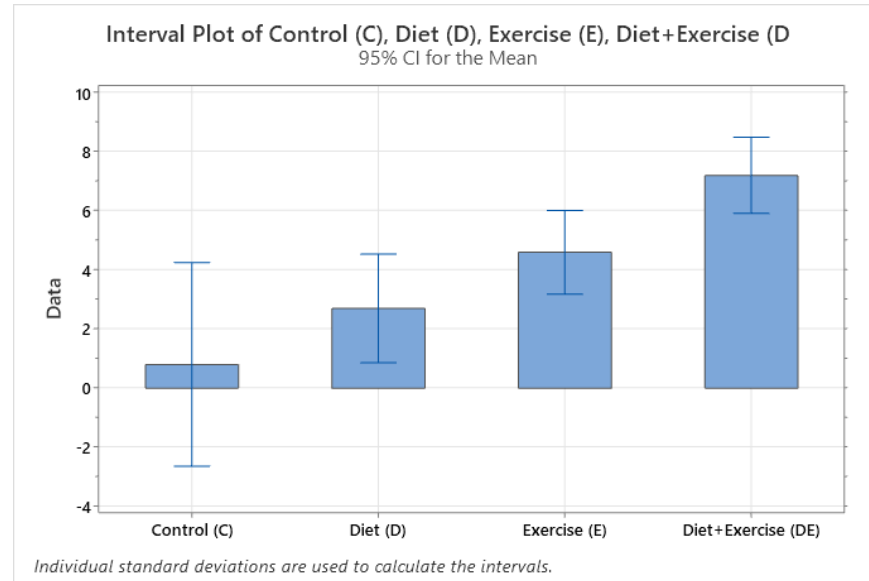
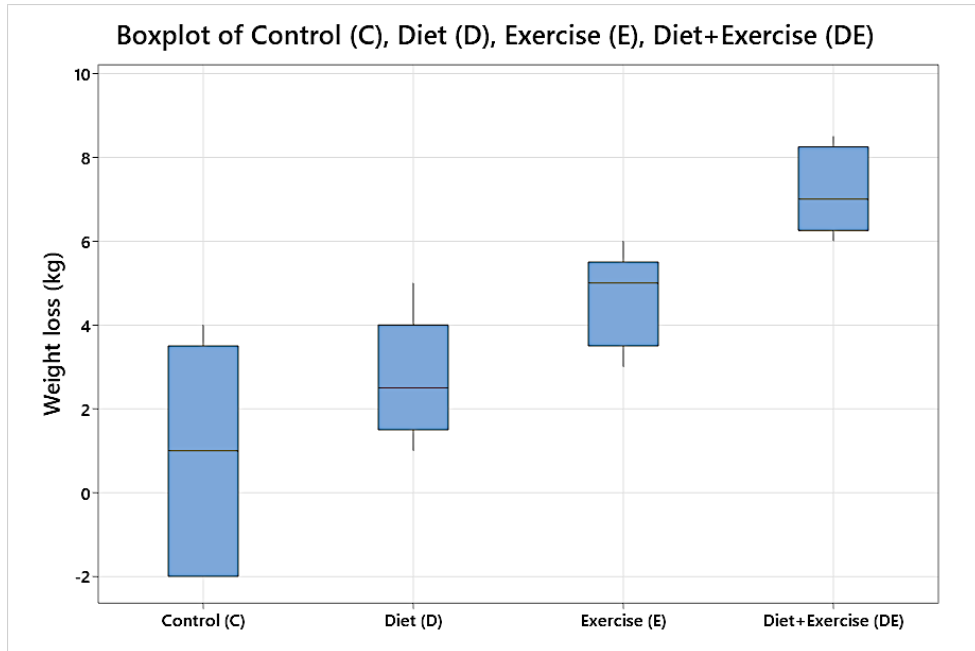


Effect of diet/exercise on weight: Results

| Group | Weight Loss (kg) | | | | | |
|--------------------|------------------|---|----|-----|-----|------|
| | | | | | | Avg. |
| Control (C) | 3 | 4 | -2 | 1 | -2 | 0.34 |
| Diet (D) | 5 | 3 | 2 | 1 | 2.5 | 2.94 |
| Exercise (E) | 6 | 4 | 5 | 3 | 5 | 4.6 |
| Diet+Exercise (DE) | 8 | 7 | 6 | 6.5 | 8.5 | 7.2 |



Effect of diet/exercise on weight: Box Plot





Effect of diet/exercise on weight loss?



4 Groups

Control, Diet, Exercise, Diet+Exercise

Dependent Variable

Weight loss

Independent Variable

Treatment: Control / Diet / Exercise / Exercise+Diet

Possible Comparisons (6)

Control vs. Diet

Control vs. Exercise

Control vs. Diet + Exercise

Diet vs. Exercise

Diet vs. Diet + Exercise

Exercise vs. Diet + Exercise

**Do any
of the treatments
work?**

Which is better?

No. of comparisons for given group size

$$n_{\text{comparisons}} = \frac{n_{\text{grps}} \times (n_{\text{grps}} - 1)}{2} \quad 6 = \frac{4 \times 3}{2}$$



Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|--------|----|--------|--------|---------|---------|
| Factor | 3 | 112.04 | 37.346 | 12.17 | 0.000 |
| Error | 16 | 49.10 | 3.069 | | |
| Total | 19 | 161.14 | | | |

Tukey Simultaneous Tests for Differences of Means

| Difference of Levels | Difference of Means | SE of Difference | 95% CI | T-Value | Adjusted P-Value |
|-----------------------------|---------------------|------------------|---------------|---------|------------------|
| Diet (D) - Control (C) | 1.90 | 1.11 | (-1.27, 5.07) | 1.71 | 0.348 |
| Exercise (E) - Control (C) | 3.80 | 1.11 | (0.63, 6.97) | 3.43 | 0.016 |
| Diet+Exercis - Control (C) | 6.40 | 1.11 | (3.23, 9.57) | 5.78 | 0.000 |
| Exercise (E) - Diet (D) | 1.90 | 1.11 | (-1.27, 5.07) | 1.71 | 0.348 |
| Diet+Exercis - Diet (D) | 4.50 | 1.11 | (1.33, 7.67) | 4.06 | 0.005 |
| Diet+Exercis - Exercise (E) | 2.60 | 1.11 | (-0.57, 5.77) | 2.35 | 0.129 |

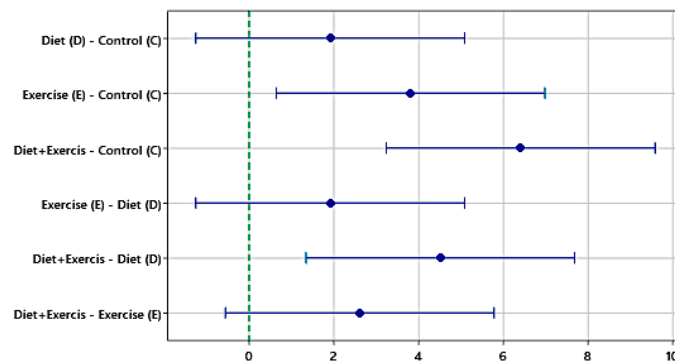
Individual confidence level = 98.87%

Fisher Individual Tests for Differences of Means

| Difference of Levels | Difference of Means | SE of Difference | 95% CI | T-Value | Adjusted P-Value |
|-----------------------------|---------------------|------------------|---------------|---------|------------------|
| Diet (D) - Control (C) | 1.90 | 1.11 | (-0.45, 4.25) | 1.71 | 0.106 |
| Exercise (E) - Control (C) | 3.80 | 1.11 | (1.45, 6.15) | 3.43 | 0.003 |
| Diet+Exercis - Control (C) | 6.40 | 1.11 | (4.05, 8.75) | 5.78 | 0.000 |
| Exercise (E) - Diet (D) | 1.90 | 1.11 | (-0.45, 4.25) | 1.71 | 0.106 |
| Diet+Exercis - Diet (D) | 4.50 | 1.11 | (2.15, 6.85) | 4.06 | 0.001 |
| Diet+Exercis - Exercise (E) | 2.60 | 1.11 | (0.25, 4.95) | 2.35 | 0.032 |

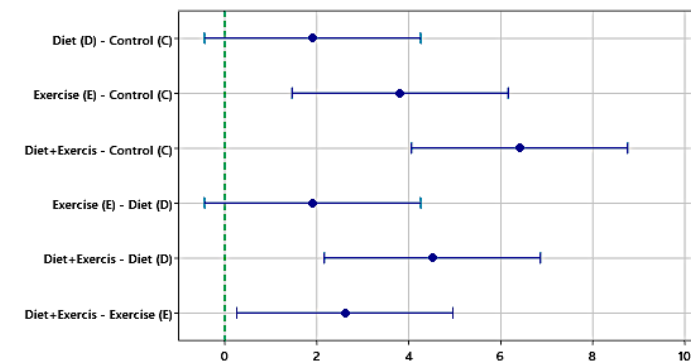
Simultaneous confidence level = 81.11%

Tukey Simultaneous 95% CIs
Difference of Means for Control (C), Diet (D), ...



If an interval does not contain zero, the corresponding means are significantly different.

Fisher Individual 95% CIs
Difference of Means for Control (C), Diet (D), ...



If an interval does not contain zero, the corresponding means are significantly different.



$$\text{LSD}_{0.05} = \sqrt{\frac{2(MS)}{n}} \quad =??$$

Significant differences between groups indicated by asterisks and lines joining bars

*** P < 0.05**

**** P < 0.01**

