Chapter 215

Paired T-Test for Superiority by a Margin

Introduction
This procedure provides reports for making inference about the superiority of a treatment over a control by a given margin from paired data. The question of interest is whether the mean of treatments minus controls is larger than some superiority margin. Another way of saying this is that the treatment is better than the control by some value called the margin.

Two different test statistics may be used: the parametric Paired T-Test and the nonparametric Wilcoxon Signed-Rank Test.

Technical Details
Suppose you want to evaluate the superiority of a continuous random variable $X_T$ as compared to a second paired random variable $X_C$. Assume that $n$ paired observations $(X_{Tk}, X_{Ck})$, $k = 1, 2, \ldots, n$ are available. The $D$'s are the differences formed as $D = X_T - X_C$.

Superiority by a Margin Test
This discussion is based on the book by Rothmann, Wiens, and Chan (2012) which discusses the two-independent sample case. These results are easily applied to the paired case.

Assume that higher values are better, that $\mu_D = \mu_{T-C}$ represent the mean of the differences between the two variables, and that $M$ is the positive superiority margin. The null and alternative hypotheses are

\begin{align*}
H_0: \mu_D &\leq M \\
H_1: \mu_D &> M
\end{align*}

If, on the other hand, we assume that higher values are worse, then null and alternative hypotheses are

\begin{align*}
H_0: \mu_D &\geq -M \\
H_1: \mu_D &< -M
\end{align*}

The paired t-test usually tests that the mean difference is zero. The superiority test compares the difference to a non-zero quantity $M$. This test can also be computed using the Paired T-Test procedure.
Assumptions
This section describes the assumptions that are made when you use each of the tests of this procedure. The key assumption relates to normality or non-normality of the data. One of the reasons for the popularity of the t-test is its robustness in the face of assumption violation. Unfortunately, in practice it often happens that more than one assumption is not met. Hence, take the steps to check the assumptions before you make important decisions based on these tests. There are reports in this procedure that permit you to examine the assumptions, both visually and through assumptions tests.

Paired T-Test Assumptions
The assumptions of the paired t-test are:

1. The data are continuous (not discrete).
2. The data, i.e., the differences for the matched-pairs, follow a normal probability distribution.
3. The sample of pairs is a simple random sample from its population. Each individual in the population has an equal probability of being selected in the sample.

Wilcoxon Signed-Rank Test Assumptions
The assumptions of the Wilcoxon signed-rank test are as follows (note that the difference is between the two data values of a pair):

1. The differences are continuous (not discrete).
2. The distribution of these differences is symmetric.
3. The differences are mutually independent.
4. The differences all have the same median.
5. The measurement scale is at least interval.

Data Structure
For this procedure, the data are entered in two columns.

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>53</td>
</tr>
<tr>
<td>63</td>
<td>69</td>
</tr>
<tr>
<td>66</td>
<td>63</td>
</tr>
<tr>
<td>74</td>
<td>76</td>
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<td>77</td>
<td>79</td>
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<tr>
<td>78</td>
<td>77</td>
</tr>
<tr>
<td>79</td>
<td>77</td>
</tr>
<tr>
<td>80</td>
<td>81</td>
</tr>
</tbody>
</table>
Example 1 – Superiority by a Margin Test using Paired Data

This section presents an example of how to test superiority by a margin. Suppose two measurements were made on each of 100 subjects. The control measurement (Method2) was made by a lengthy, invasive method and the treatment measurement (Method1) was made by a much less invasive method. The data are in the Bland-Altman dataset. The researchers wish to show that the treatment response is better than the control response by a margin of 0.5 on average.

Setup

To run this example, complete the following steps:

1. **Open the Bland-Altman example dataset**
   - From the File menu of the NCSS Data window, select Open Example Data.
   - Select Bland-Altman and click OK.

2. **Specify the Paired T-Test for Superiority by a Margin procedure options**
   - Find and open the Paired T-Test for Superiority by a Margin procedure using the menus or the Procedure Navigator.
   - The settings for this example are listed below and are stored in the Example 1 settings template. To load this template, click Open Example Template in the Help Center or File menu.

<table>
<thead>
<tr>
<th>Option</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables Tab</td>
<td></td>
</tr>
<tr>
<td>Treatment Variable</td>
<td>Method1</td>
</tr>
<tr>
<td>Control Variable</td>
<td>Method2</td>
</tr>
<tr>
<td>Higher Values Are</td>
<td>Better</td>
</tr>
<tr>
<td>Superiority Margin</td>
<td>0.5</td>
</tr>
<tr>
<td>Reports Tab</td>
<td></td>
</tr>
<tr>
<td>Wilcoxon Signed-Rank Test</td>
<td>Checked</td>
</tr>
</tbody>
</table>

3. **Run the procedure**
   - Click the Run button to perform the calculations and generate the output.

Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Count</th>
<th>Mean</th>
<th>Standard Deviation of Data</th>
<th>Standard Error of Mean</th>
<th>95.0% LCL of Mean</th>
<th>95.0% UCL of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method1</td>
<td>100</td>
<td>50.72</td>
<td>28.30893</td>
<td>2.830893</td>
<td>45.10289</td>
<td>56.3371</td>
</tr>
<tr>
<td>Method2</td>
<td>100</td>
<td>50.62</td>
<td>28.07701</td>
<td>2.807702</td>
<td>45.04891</td>
<td>56.19109</td>
</tr>
<tr>
<td>Difference</td>
<td>100</td>
<td>0.1</td>
<td>2.787055</td>
<td>0.2787055</td>
<td>-0.4530122</td>
<td>0.6530122</td>
</tr>
</tbody>
</table>

Correlation Coefficient = 0.995147

This report provides basic descriptive statistics and confidence intervals for the two variables and their difference.

**Variable**
These are the names of the variables or groups.
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Count
The count gives the number of non-missing values. This value is often referred to as the group sample size or $n$.

Mean
This is the average for each group.

Standard Deviation
The sample standard deviation is the square root of the sample variance. It is a measure of spread.

Standard Error
This is the estimated standard deviation for the distribution of sample means for an infinite population. It is the sample standard deviation divided by the square root of sample size, $n$.

T*
This is the t-value used to construct the confidence interval. If you were constructing the interval manually, you would obtain this value from a table of the Student’s t distribution with $n - 1$ degrees of freedom.

LCL and UCL of the Mean
This is the lower limit of an interval estimate of the mean based on a Student’s t distribution with $n - 1$ degrees of freedom. This interval estimate assumes that the population standard deviation is not known and that the data are normally distributed. The confidence interval formula is

$$\bar{x} \pm t_{df} \cdot SE\bar{x}$$

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<table>
<thead>
<tr>
<th>Alternative Hypothesis</th>
<th>Mean Difference</th>
<th>Standard Error</th>
<th>T-Statistic</th>
<th>DF</th>
<th>Prob Level</th>
<th>Conclude Superiority at $\alpha = 0.050$?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Diff. &gt; 0.5</td>
<td>0.1</td>
<td>0.2787055</td>
<td>-1.4352</td>
<td>99</td>
<td>0.92281</td>
<td>No</td>
</tr>
</tbody>
</table>

This report shows the parametric paired T-Test for superiority by a margin. Since the Prob Level is greater than the designated value of alpha (0.05), we cannot reject null hypothesis. We cannot conclude that the new treatment is superior to the standard. This test assumes that the differences are normal.

Alternative Hypothesis
Assume that $\mu_D = \mu_{T-C}$ represents the mean of the differences between the two variables and that $M$ is the positive superiority margin. If **higher values are better**, then the null and alternative hypotheses are

$$H0: \mu_D \leq M$$
$$H1: \mu_D > M$$

If **higher values are worse**, then null and alternative hypotheses are

$$H0: \mu_D \geq -M$$
$$H1: \mu_D < -M$$

In practice, the alternative hypothesis should be chosen in advance.

Mean Difference
This is the average of the paired differences, $\bar{x}_D$.  

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**Standard Error**

This is the estimated standard deviation of the distribution of sample means for an infinite population.

\[ SE_{\bar{X}_D} = \frac{s_D}{\sqrt{n}} \]

**T-Statistic**

The T-Statistic is the value used to produce the p-value (Prob Level) based on the T distribution. The formula for the T-Statistic is:

\[ T = \frac{\bar{X}_D - M}{SE_{\bar{X}_D}} \]

**DF**

The degrees of freedom define the T distribution upon which the probability values are based. The formula for the degrees of freedom is the number of pairs minus one:

\[ df = n - 1 \]

**Prob Level**

The probability level, also known as the p-value or significance level, is the probability that the test statistic will take a value at least as extreme as the observed value, assuming that the null hypothesis is true. If the p-value is less than the prescribed \( \alpha \), in this case 0.05, the null hypothesis is rejected in favor of the alternative hypothesis. Otherwise, there is not sufficient evidence to reject the null hypothesis.

**Conclude Superiority at \( \alpha = 0.050 \)?**

This column indicates whether or not the null hypothesis is rejected, in favor of the alternative hypothesis, based on the p-value and chosen \( \alpha \). A test in which the null hypothesis is rejected is sometimes called significant.

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### Wilcoxon Signed-Rank Test for Superiority by a Margin

**Higher Values are Better**

Superiority Hypothesis: \([\text{Median of (Method1)} - \text{(Method2)}] > 0.5\)

<table>
<thead>
<tr>
<th>Sum of Ranks (W)</th>
<th>Mean of W</th>
<th>Std Dev of W</th>
<th>Number of Observations</th>
<th>Number of Zeros</th>
<th>Number of Sets of Ties</th>
<th>Multiplicity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2124.5</td>
<td>2525</td>
<td>288.1547</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>74610</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Alternative Hypothesis</th>
<th>Z-Value</th>
<th>Prob Level</th>
<th>Conclude Superiority at ( \alpha = 0.050 )?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact*</td>
<td>Median Diff. &gt; 0.5</td>
<td>-1.3899</td>
<td>0.91772</td>
<td>No</td>
</tr>
<tr>
<td>Normal Approximation</td>
<td>Median Diff. &gt; 0.5</td>
<td>-1.3916</td>
<td>0.91798</td>
<td>No</td>
</tr>
<tr>
<td>Normal Approx. with C.C.</td>
<td>Median Diff. &gt; 0.5</td>
<td>-1.3916</td>
<td>0.91798</td>
<td>No</td>
</tr>
</tbody>
</table>

* The Exact Test is provided only when there are no ties.

This report shows the nonparametric Wilcoxon Signed-Rank Test for superiority by a margin. Since the Prob Level is greater than the designated value of alpha (0.05), we cannot reject null hypothesis and cannot conclude that the new treatment is superior to the standard. This test required no assumption that the differences are normal.

**Sum of Ranks (W)**

The basic statistic for this test is the sum of the positive ranks, \( \sum R_+ \). (The sum of the positive ranks is chosen arbitrarily. The sum of the negative ranks could equally be used). This statistic is called \( W \).

\[ W = \sum R_+ \]
Mean of \( W \)
This is the mean of the sampling distribution of the sum of ranks for a sample of \( n \) items.

\[
\mu_W = \frac{n(n + 1) - d_0(d_0 + 1)}{4}
\]

where \( d_0 \) is the number of zero differences.

Std Dev of \( W \)
This is the standard deviation of the sampling distribution of the sum of ranks. Here \( t_i \) represents the number of times the \( i^{th} \) value occurs.

\[
s_W = \sqrt{\frac{n(n + 1)(2n + 1) - d_0(d_0 + 1)(2d_0 + 1)}{24} - \frac{\sum t_i^3 - \sum t_i}{48}}
\]

where \( d_0 \) is the number zero differences, \( t_i \) is the number of absolute differences that are tied for a given non-zero rank, and the sum is over all sets of tied ranks.

Number of Zeros
This is the number of times that the difference between the observed paired difference and the hypothesized value is zero. The zeros are used in computing ranks, but are not considered positive ranks or negative ranks.

Number Sets of Ties
The treatment of ties is to assign an average rank for the particular set of ties. This is the number of sets of ties that occur in the data, including ties at zero.

Multiplicity Factor
This is the correction factor that appeared in the standard deviation of the sum of ranks when there were ties.

Test Type
This is the type of test that is being reported on the current row. The Exact Test is provided only when there are no ties.

Alternative Hypothesis
For the Wilcoxon signed-rank test, the null and alternative hypotheses relate to the median. The left-tail alternative is represented by Median < -M (i.e., \( H_a: \) median < -M) while the right-tail alternative is depicted by Median > M.

Exact Probability: Prob Level
This is an exact \( p \)-value for this statistical test, assuming no ties. The \( p \)-value is the probability that the test statistic will take on a value at least as extreme as the actually observed value, assuming that the null hypothesis is true. If the \( p \)-value is less than \( \alpha \), say 5%, the null hypothesis is rejected. If the \( p \)-value is greater than \( \alpha \), the null hypothesis is accepted.

Exact Probability: Reject \( H_0 \) (\( \alpha = 0.050 \))
This is the conclusion reached about the null hypothesis. It will be to either fail to reject \( H_0 \) or reject \( H_0 \) at the assigned level of significance.
Approximations with (and without) Continuity Correction: Z-Value

Given the sample size is at least ten, a normal approximation method may be used to approximate the distribution of the sum of ranks. Although this method does correct for ties, it does not have the continuity correction factor. The z value is as follows:

\[ z = \frac{W - \mu_W}{\sigma_W} \]

If the correction factor for continuity is used, the formula becomes:

\[ z = \frac{W - \mu_W \pm \frac{1}{2}}{\sigma_W} \]

Approximations with (and without) Continuity Correction: Prob Level

This is the p-value for the normal approximation approach for the Wilcoxon signed-rank test. The p-value is the probability that the test statistic will take a value at least as extreme as the actually observed value, assuming that the null hypothesis is true. If the p-value is less than \( \alpha \), say 5%, the null hypothesis is rejected. If the p-value is greater than \( \alpha \), the null hypothesis is accepted.

Approximations with (and without) Continuity Correction: Reject H0 (\( \alpha = 0.050 \))

This is the conclusion reached about the whether to reject null hypothesis. It will be either Yes or No at the given level of significance.

Test of Assumptions

<table>
<thead>
<tr>
<th>Test of the Normality of Differences Assumption</th>
<th>Normality Test</th>
<th>Value</th>
<th>Prob Level</th>
<th>Decision (( \alpha = 0.050 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shapiro-Wilk</td>
<td>0.8926</td>
<td>0.0000</td>
<td>Reject normality</td>
<td></td>
</tr>
</tbody>
</table>

The main assumption when using the t-test is that the paired-difference data come from a normal distribution. The normality assumption can be checked statistically by the Shapiro-Wilk normality test and visually by the histogram or normal probability plot.

This section reports the results of a diagnostic test to determine if the differences are normal. In this case, they are not, probably because of the outliers that were present. This would indicate that the Wilcoxon Signed-Rank Test would be the better test to use.
The nonparametric tests need the assumption of symmetry, and these two graphic tools can provide that information. If the distribution of differences is symmetrical but not normal, proceed with the nonparametric test.

If any of the observations fall outside the confidence bands (if shown), the data are not normal. The goodness-of-fit tests mentioned earlier, especially the omnibus test, should confirm this fact statistically. If only one observation falls outside the confidence bands and the remaining observations hug the straight line, there may be an outlier. If the data were normal, we would see the points falling along a straight line.

Note that the confidence bands are based on large-sample formulas. They may not be accurate for small samples.
Scatter Plot of Pairs

This plot allows you to look for patterns between the pairs. Preferably, you would like to see either no correlation or a positive linear correlation between Y and X. If there is a curvilinear relationship between Y and X, the paired t-test is not appropriate. If there is a negative relationship between the observations in the pairs, the paired t-test is not appropriate. If there are outliers, a nonparametric approach might be safer.

Average vs Difference Plot

This average-difference plot is designed to detect a lack of symmetry in the data. This plot is constructed from the paired differences, not the original data. Here’s how: Let D(i) represent the ith ordered difference. Pairs of these
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sorted differences are considered, with the pairing being done as you move toward the middle from either end. That is, consider the pairs D(1) and D(n), D(2) and D(n-1), D(3) and D(n-2), etc. Plot the average versus the difference of each of these pairs. Your plot will have about n/2 points, depending on whether n is odd or even. If the data are symmetric, the average of each pair will be the median and the difference between each pair will be zero.

Symmetry is an important assumption for the t-test. A perfectly symmetric set of data should show a vertical line of points hitting the horizontal axis at the value of the median. Departures from symmetry would deviate from this standard.