

# **SAS/STAT<sup>®</sup> 14.2 User's Guide**

## **The TTEST Procedure**

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#### **SAS/STAT® 14.2 User's Guide**

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# Chapter 121

## The TTEST Procedure

### Contents

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Overview: TTEST Procedure . . . . .	<b>9902</b>
Getting Started: TTEST Procedure . . . . .	<b>9903</b>
One-Sample $t$ Test . . . . .	9903
Comparing Group Means . . . . .	9905
Syntax: TTEST Procedure . . . . .	<b>9909</b>
PROC TTEST Statement . . . . .	9910
BY Statement . . . . .	9917
CLASS Statement . . . . .	9918
FREQ Statement . . . . .	9918
PAIRED Statement . . . . .	9918
VAR Statement . . . . .	9919
WEIGHT Statement . . . . .	9920
Details: TTEST Procedure . . . . .	<b>9920</b>
Input Data Set of Statistics . . . . .	9920
Missing Values . . . . .	9920
Computational Methods . . . . .	9921
Common Notation . . . . .	9921
Arithmetic and Geometric Means . . . . .	9921
Coefficient of Variation . . . . .	9922
One-Sample Design . . . . .	9922
Paired Design . . . . .	9925
Two-Independent-Sample Design . . . . .	9926
AB/BA Crossover Design . . . . .	9931
TOST Equivalence Test . . . . .	9932
Displayed Output . . . . .	9932
ODS Table Names . . . . .	9936
ODS Graphics . . . . .	9936
ODS Graph Names . . . . .	9936
Interpreting Graphs . . . . .	9937
Examples: TTEST Procedure . . . . .	<b>9940</b>
Example 121.1: Using Summary Statistics to Compare Group Means . . . . .	9940
Example 121.2: One-Sample Comparison with the FREQ Statement . . . . .	9942
Example 121.3: Paired Comparisons . . . . .	9945
Example 121.4: AB/BA Crossover Design . . . . .	9950
Example 121.5: Equivalence Testing with Lognormal Data . . . . .	9959
References . . . . .	<b>9964</b>

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## Overview: TTEST Procedure

The TTEST procedure performs  $t$  tests and computes confidence limits for one sample, paired observations, two independent samples, and the AB/BA crossover design. Two-sided, TOST (two one-sided test) equivalence, and upper and lower one-sided hypotheses are supported for means, mean differences, and mean ratios for either normal or lognormal data.

Table 121.1 summarizes the designs, analysis criteria, hypotheses, and distributional assumptions supported in the TTEST procedure, along with the syntax used to specify them.

**Table 121.1** Features Supported in the TTEST Procedure

Feature	Syntax
<b>Design</b>	
One-sample	VAR statement
Paired	PAIRED statement
Two-independent-sample	CLASS statement, VAR statement
AB/BA crossover	VAR / CROSSOVER=
<b>Analysis Criterion</b>	
Mean difference	PROC TTEST TEST=DIFF
Mean ratio	PROC TTEST TEST=RATIO
<b>Hypothesis</b>	
Two-sided	PROC TTEST SIDES=2
Equivalence	PROC TTEST TOST ( < lower , > upper )
Lower one-sided	PROC TTEST SIDES=L
Upper one-sided	PROC TTEST SIDES=U
<b>Distribution</b>	
Normal	PROC TTEST DIST=NORMAL
Lognormal	PROC TTEST DIST=LOGNORMAL

FREQ and WEIGHT statements are available. Data can be input in the form of observations or, in certain cases, summary statistics. Output includes summary statistics; confidence limits for means, standard deviations, and coefficients of variation; hypothesis tests; and a variety of graphical displays, including histograms, densities, box plots, confidence intervals, Q-Q plots, profiles, and agreement plots.

PROC TTEST uses ODS Graphics to create graphs as part of its output. For general information about ODS Graphics, see Chapter 21, “Statistical Graphics Using ODS.” For specific information about the statistical graphics available with the TTEST procedure, see the PLOTS option in the PROC TTEST statement and the section “ODS Graphics” on page 9936.

## Getting Started: TTEST Procedure

### One-Sample *t* Test

A one-sample *t* test can be used to compare a sample mean to a given value. This example, taken from Huntsberger and Billingsley (1989, p. 290), tests whether the mean length of a certain type of court case is more than 80 days by using 20 randomly chosen cases. The data are read by the following DATA step:

```
data time;
  input time @@;
  datalines;
  43 90 84 87 116 95 86 99 93 92
  121 71 66 98 79 102 60 112 105 98
  ;
```

The only variable in the data set, *time*, is assumed to be normally distributed. The trailing at signs ( @@ ) indicate that there is more than one observation on a line. The following statements invoke PROC TTEST for a one-sample *t* test:

```
ods graphics on;

proc ttest h0=80 plots(showh0) sides=u alpha=0.1;
  var time;
run;

ods graphics off;
```

The **VAR** statement indicates that the *time* variable is being studied, while the **H0=** option specifies that the mean of the *time* variable should be compared to the null value 80 rather than the default of 0. The **PLOTS(SHOWH0)** option requests that this null value be displayed on all relevant graphs. The **SIDES=U** option reflects the focus of the research question, namely whether the mean court case length is *greater than* 80 days, rather than *different than* 80 days (in which case you would use the default **SIDES=2** option). The **ALPHA=0.1** option requests 90% confidence intervals rather than the default 95% confidence intervals. The output is displayed in Figure 121.1.

**Figure 121.1** One-Sample *t* Test Results

#### The TTEST Procedure

Variable: *time*

N	Mean	Std Dev	Std Err	Minimum	Maximum
20	89.8500	19.1456	4.2811	43.0000	121.0

		90%		90%	
Mean	CL Mean	Std Dev	CL Std Dev		
89.8500	84.1659	Infy	19.1456	15.2002	26.2374

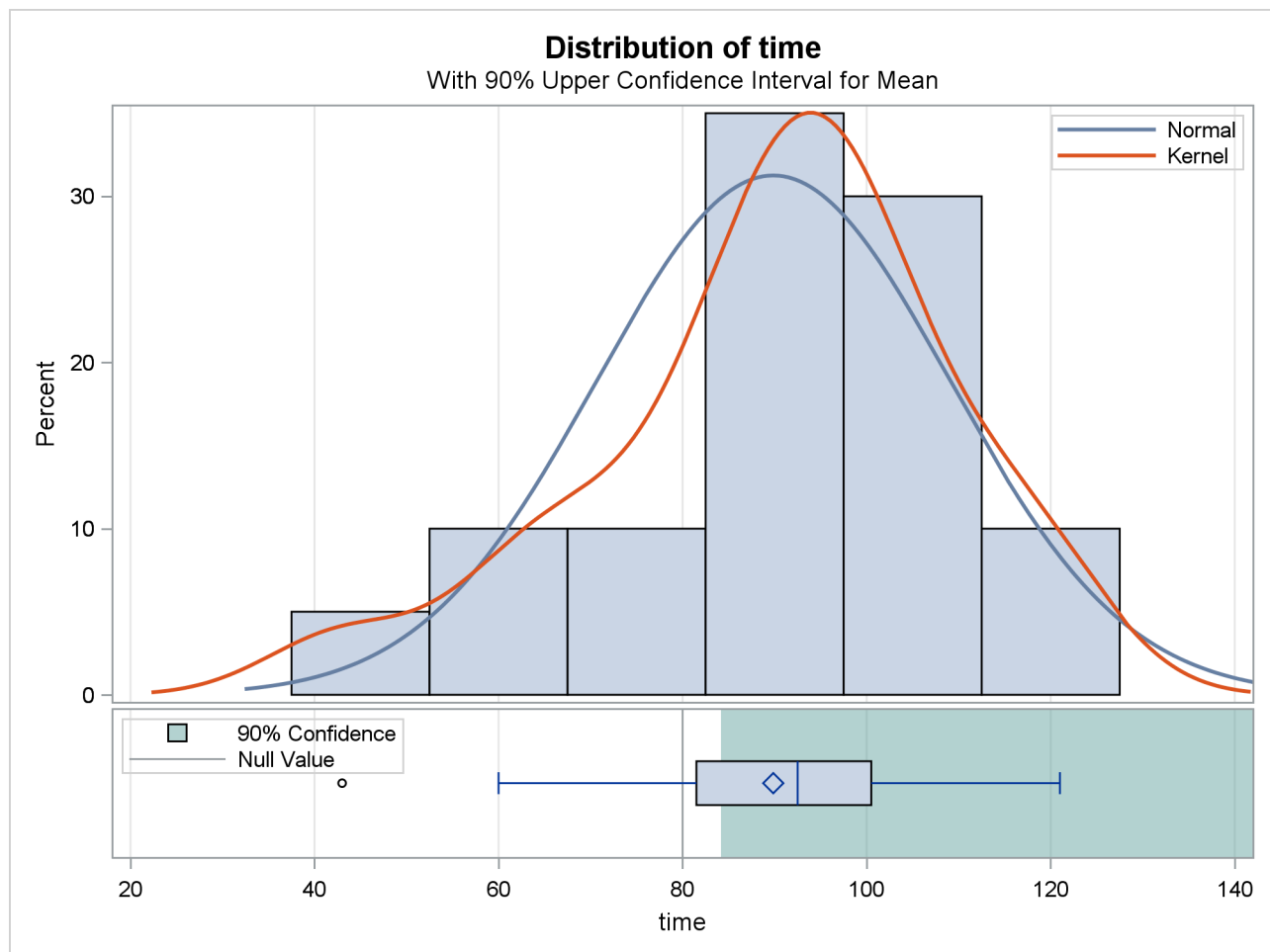
  

DF	t Value	Pr > t
19	2.30	0.0164

Summary statistics appear at the top of the output. The sample size (N), mean, standard deviation, and standard error are displayed with the minimum and maximum values of the time variable. The 90% confidence limits for the mean and standard deviation are shown next. Due to the `SIDES=U` option, the interval for the mean is an upper one-sided interval with a finite lower bound (84.1659 days). The limits for the standard deviation are the equal-tailed variety, per the default `CI=EQUAL` option in the `PROC TTEST` statement. At the bottom of the output are the degrees of freedom,  $t$  statistic value, and  $p$ -value for the  $t$  test. At the 10%  $\alpha$  level, this test indicates that the mean length of the court cases is significantly greater than from 80 days ( $t = 2.30$ ,  $p = 0.0164$ ).

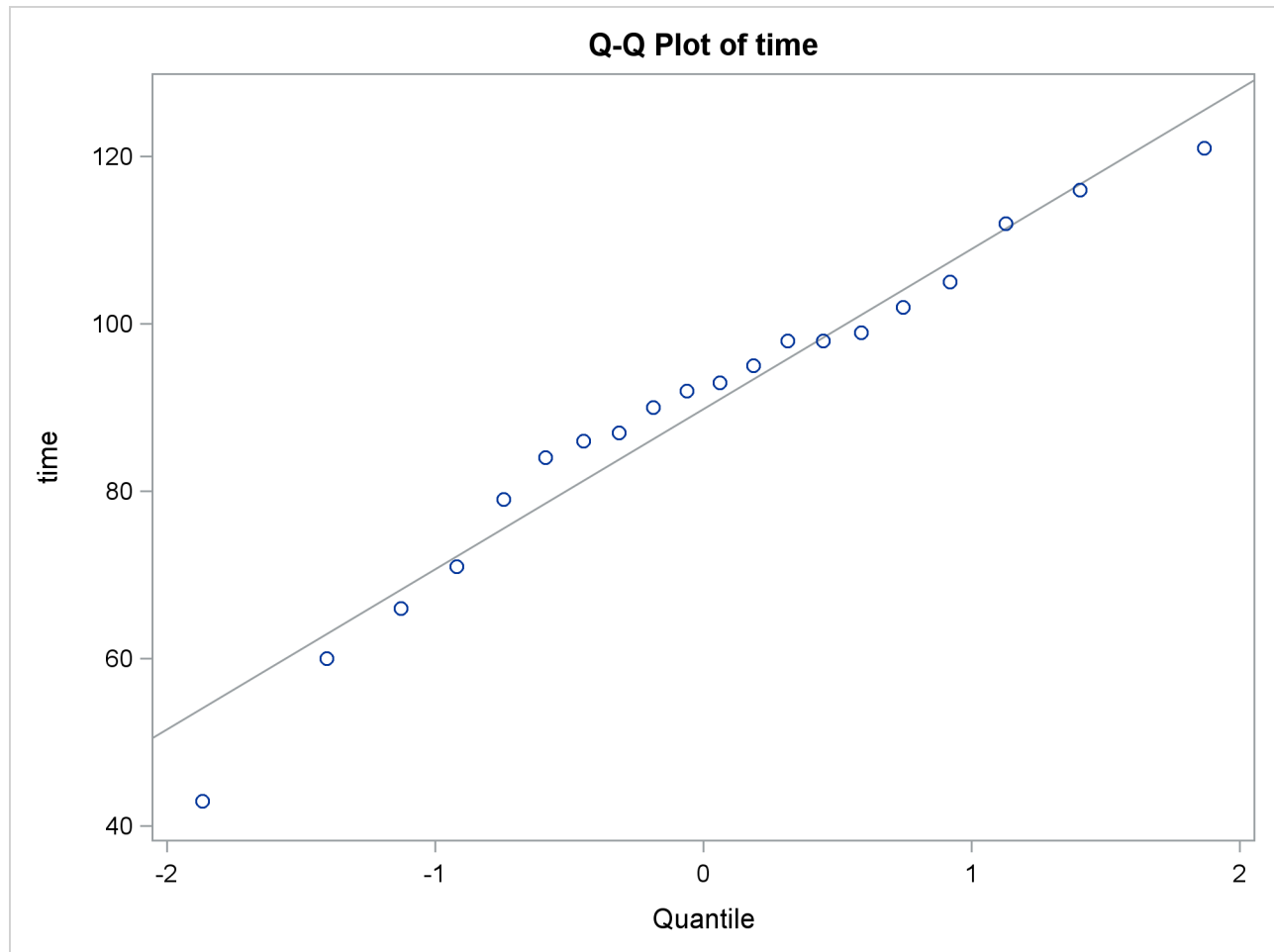
The summary panel in Figure 121.2 shows a histogram with overlaid normal and kernel densities, a box plot, the 90% confidence interval for the mean, and the null value of 80 days.

**Figure 121.2** Summary Panel



The confidence interval excludes the null value, consistent with the rejection of the null hypothesis at  $\alpha = 0.1$ .

The Q-Q plot in Figure 121.3 assesses the normality assumption.

**Figure 121.3** Q-Q Plot

The curvilinear shape of the Q-Q plot suggests a possible slight deviation from normality. You could use the UNIVARIATE procedure with the NORMAL option to numerically check the normality assumptions.

## Comparing Group Means

If you want to compare values obtained from two different groups, and if the groups are independent of each other and the data are normally or lognormally distributed in each group, then a group  $t$  test can be used. Examples of such group comparisons include the following:

- test scores for two third-grade classes, where one of the classes receives tutoring
- fuel efficiency readings of two automobile nameplates, where each nameplate uses the same fuel
- sunburn scores for two sunblock lotions, each applied to a different group of people
- political attitude scores of males and females

In the following example, the golf scores for males and females in a physical education class are compared. The sample sizes from each population are equal, but this is not required for further analysis. The scores

are thought to be approximately normally distributed within gender. The data are read by the following statements:

```
data scores;
  input Gender $ Score @@;
  datalines;
f 75 f 76 f 80 f 77 f 80 f 77 f 73
m 82 m 80 m 85 m 85 m 78 m 87 m 82
;
```

The dollar sign (\$) following Gender in the INPUT statement indicates that Gender is a character variable. The trailing at signs (@@) enable the procedure to read more than one observation per line.

You can use a group *t* test to determine whether the mean golf score for the men in the class differs significantly from the mean score for the women. If you also suspect that the distributions of the golf scores of males and females have unequal variances, then you might want to specify the **COCHRAN** option in order to use the Cochran approximation (in addition to the Satterthwaite approximation, which is included by default). The following statements invoke PROC TTEST for the case of unequal variances, along with both types of confidence limits for the pooled standard deviation.

```
ods graphics on;

proc ttest cochrans ci=equal umpu;
  class Gender;
  var Score;
run;

ods graphics off;
```

The **CLASS** statement contains the variable that distinguishes the groups being compared, and the **VAR** statement specifies the response variable to be used in calculations. The **COCHRAN** option produces *p*-values for the unequal variance situation by using the Cochran and Cox (1950) approximation. Equal-tailed and uniformly most powerful unbiased (UMPU) confidence intervals for  $\sigma$  are requested by the **CI=** option. Output from these statements is displayed in Figure 121.4 through Figure 121.7.

**Figure 121.4** Simple Statistics

#### The TTEST Procedure

Variable: Score

Gender	N	Mean	Std Dev	Std Err	Minimum	Maximum
f	7	76.8571	2.5448	0.9619	73.0000	80.0000
m	7	82.7143	3.1472	1.1895	78.0000	87.0000
Diff (1-2)		-5.8571	2.8619	1.5298		

Simple statistics for the two populations being compared, as well as for the difference of the means between the populations, are displayed in Figure 121.4. The Gender column indicates the population corresponding to the statistics in that row. The sample size (N), mean, standard deviation, standard error, and minimum and maximum values are displayed.

Confidence limits for means and standard deviations are shown in Figure 121.5.



**Figure 121.5** Simple Statistics

Gender	Method			Std Dev	95%		95%		Std Dev
		Mean	95% CL Mean		CL	Std Dev	UMPU CL	Std Dev	
f		76.8571	74.5036 79.2107	2.5448	1.6399	5.6039	1.5634	5.2219	
m		82.7143	79.8036 85.6249	3.1472	2.0280	6.9303	1.9335	6.4579	
Diff (1-2) Pooled		-5.8571	-9.1902 -2.5241	2.8619	2.0522	4.7242	2.0019	4.5727	
Diff (1-2) Satterthwaite		-5.8571	-9.2064 -2.5078						

For the mean differences, both pooled (assuming equal variances for males and females) and Satterthwaite (assuming unequal variances) 95% intervals are shown. The confidence limits for the standard deviations are of the equal-tailed variety.

The test statistics, associated degrees of freedom, and  $p$ -values are displayed in [Figure 121.6](#).

**Figure 121.6**  $t$  Tests

Method	Variances	DF	t Value	Pr >  t
Pooled	Equal	12	-3.83	0.0024
Satterthwaite	Unequal	11.496	-3.83	0.0026
Cochran	Unequal	6	-3.83	0.0087

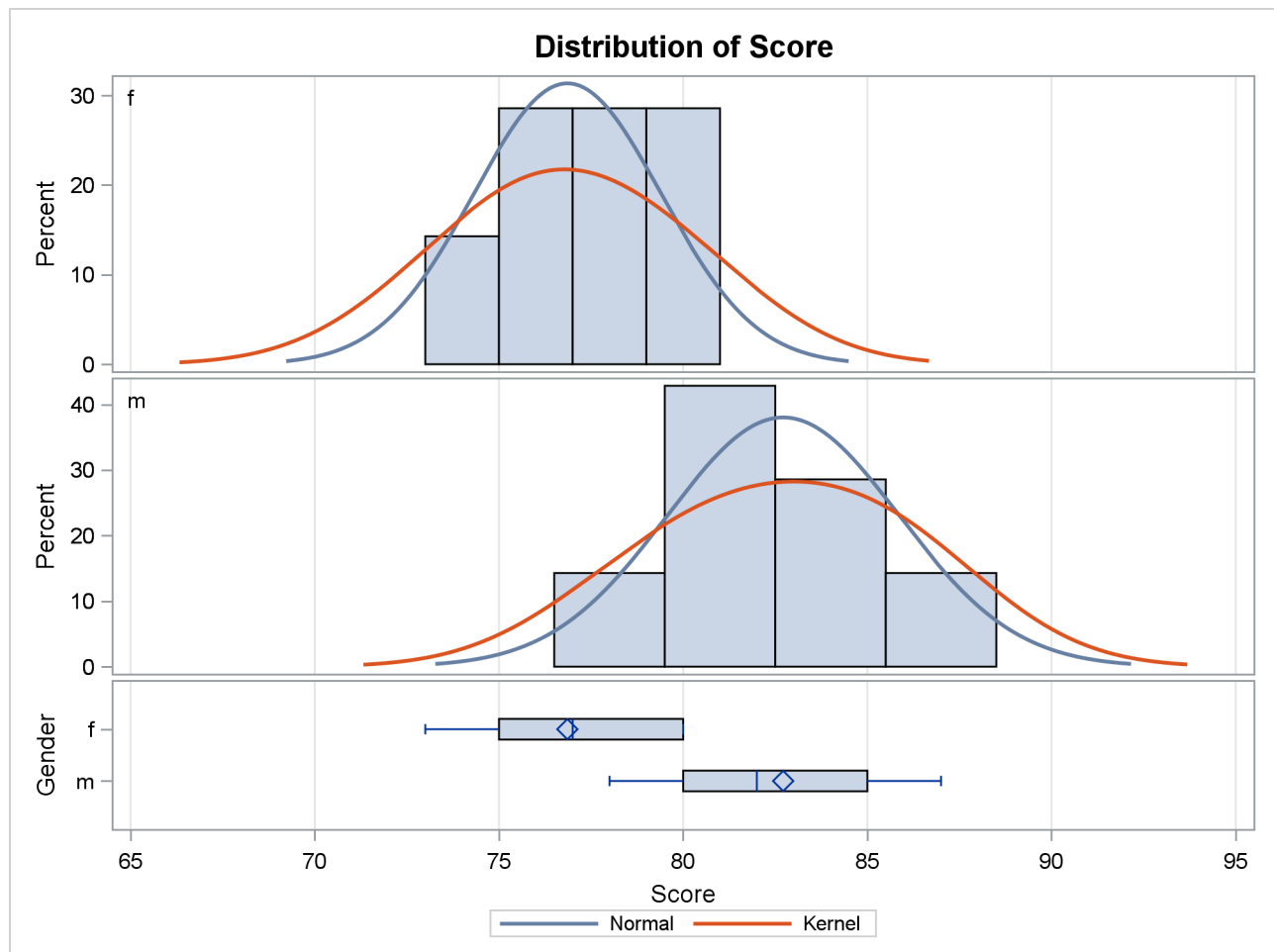
The Method column denotes which  $t$  test is being used for that row, and the Variances column indicates what assumption about variances is being made. The pooled test assumes that the two populations have equal variances and uses degrees of freedom  $n_1 + n_2 - 2$ , where  $n_1$  and  $n_2$  are the sample sizes for the two populations. The remaining two tests do not assume that the populations have equal variances. The Satterthwaite test uses the Satterthwaite approximation for degrees of freedom, while the Cochran test uses the Cochran and Cox approximation for the  $p$ -value. All three tests result in highly significant  $p$ -values, supporting the conclusion of a significant difference between males' and females' golf scores.

The “Equality of Variances” test in [Figure 121.7](#) reveals insufficient evidence of unequal variances (the Folded F statistic  $F' = 1.53$ , with  $p = 0.6189$ ).

**Figure 121.7** Tests of Equality of Variances

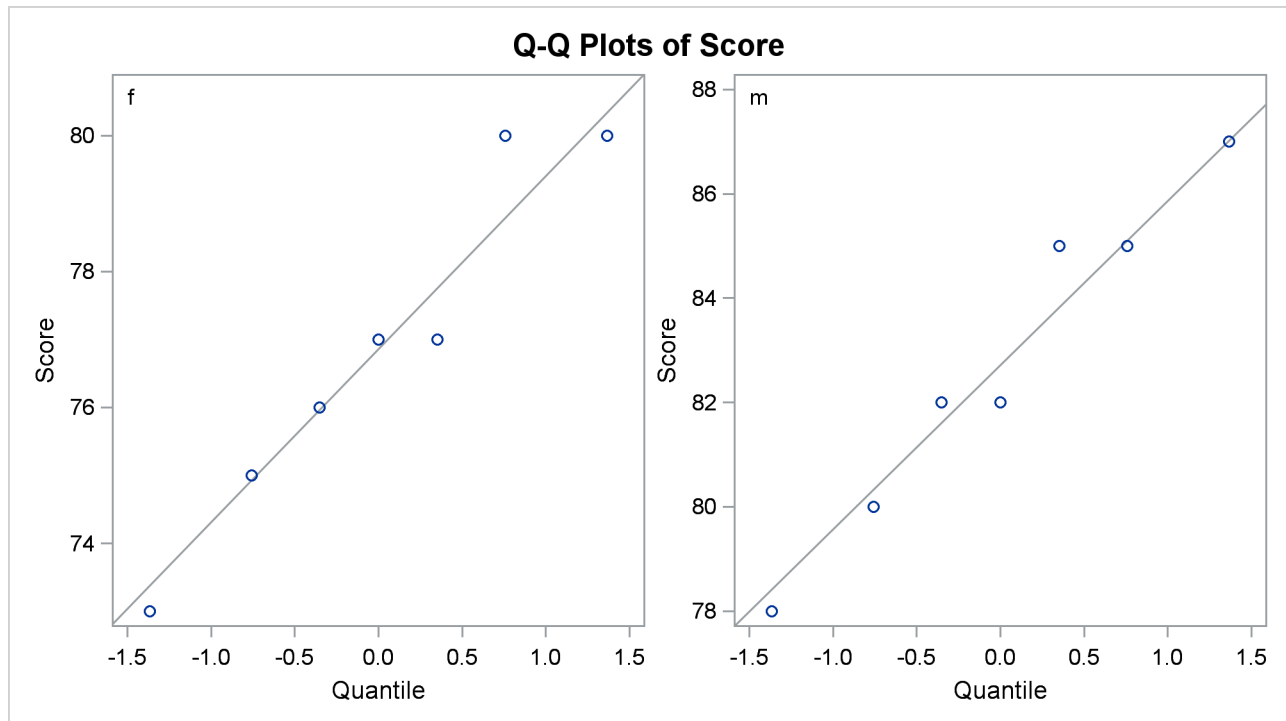
Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	6	6	1.53	0.6189

The summary panel in [Figure 121.8](#) shows comparative histograms, normal and kernel densities, and box plots, comparing the distribution of golf scores between genders.

**Figure 121.8** Summary Panel

The Q-Q plots in [Output 121.9](#) assess the normality assumption for each gender.

Figure 121.9 Q-Q Plot



The plots for both males and females show no obvious deviations from normality. You can check the assumption of normality more rigorously by using PROC UNIVARIATE with the NORMAL option; if the assumption of normality is not reasonable, you should analyze the data with the nonparametric Wilcoxon rank sum test by using PROC NPAR1WAY.

## Syntax: TTEST Procedure

The following statements are available in the TTEST procedure:

```
PROC TTEST < options > ;
  CLASS variable ;
  PAIRED variables ;
  BY variables ;
  VAR variables < / options > ;
  FREQ variable ;
  WEIGHT variable ;
```

No statement can be used more than once. There is no restriction on the order of the statements after the PROC TTEST statement. The following sections describe the PROC TTEST statement and then describe the other statements in alphabetical order.

## PROC TTEST Statement

**PROC TTEST** < options > ;

The **PROC TTEST** statement invokes the TTEST procedure. Table 121.2 summarizes the *options* available in the **PROC TTEST** statement. The *options* are then described fully in alphabetical order.

**Table 121.2** PROC TTEST Statement Options

Option	Description
<b>Basic Options</b>	
<b>DATA=</b>	Specifies input data set
<b>ORDER=</b>	Determines sort order of <b>CLASS</b> variable or <b>CROSSOVER=</b> treatment variables
<b>Analysis Options</b>	
<b>ALPHA=</b>	Specifies 1 – confidence level
<b>DIST=</b>	Specifies distributional assumption (normal or lognormal)
<b>H0=</b>	Specifies null value
<b>SIDES=</b>	Specifies number of sides and direction
<b>TEST=</b>	Specifies test criterion (difference or ratio)
<b>TOST</b>	Requests equivalence test and specifies bounds
<b>Displayed Output</b>	
<b>CI=</b>	Requests confidence interval for standard deviation or coefficient of variation
<b>COCHRAN</b>	Requests Cochran <i>t</i> test
<b>PLOTS</b>	Produces ODS statistical graphics
<b>Output Ordering</b>	
<b>BYVAR</b>	Groups results by variables that are specified in the <b>PAIRED</b> or <b>VAR</b> statement
<b>NOBYVAR</b>	Groups results by tables

You can specify the following *options*:

### **ALPHA=***p*

specifies that confidence intervals (except test-based mean confidence intervals when the **TOST** option is used) are to be  $100(1 - p)\%$  confidence intervals, where  $0 < p < 1$ . When the **TOST** option is used, the test-based mean confidence intervals are  $100(1 - 2p)\%$  confidence intervals. If *p* is 0 or less, or 1 or more, an error message is printed. By default, ALPHA=0.05.

### **BYVAR**

groups the results by the variables that are specified in the **PAIRED** or **VAR** statement. The **BYVAR** option is enabled by default. Note that this represents a change from previous releases for how the

results are grouped with respect to variables and tables. Prior to SAS 9.2, multiple variables were included in each table, similar to the new [NOBYVAR](#) option.

### **CI=EQUAL | UMPU | NONE**

### **CL=EQUAL | UMPU | NONE**

specifies whether a confidence interval is displayed for  $\sigma$  and, if so, what kind. You can specify one or more of the following values:

<b>EQUAL</b>	specifies an equal-tailed confidence interval.
<b>UMPU</b>	specifies an interval based on the uniformly most powerful unbiased test of $H_0: \sigma = \sigma_0$ .
<b>NONE</b>	requests that no confidence interval be displayed for $\sigma$ .

The values **EQUAL** and **UMPU** together request that both types of confidence intervals be displayed. If the value **NONE** is specified with one or both of the values **EQUAL** and **UMPU**, **NONE** takes precedence. For more information, see the section “[Two-Independent-Sample Design](#)” on page 9926. By default, **CI=EQUAL**.

### **COCHRAN**

requests the Cochran and Cox (1950) approximation of the probability level for the unequal variances situation. For more information, see the section “[Two-Independent-Sample Design](#)” on page 9926.

### **DATA=SAS-data-set**

names the SAS data set for the procedure to use. By default, PROC TTEST uses the most recently created SAS data set. The input data set can contain summary statistics of the observations instead of the observations themselves. The number, mean, and standard deviation of the observations are required for each **BY** group (one sample and paired differences) or for each class within each **BY** group (two samples). For more information about the **DATA=** option, see the section “[Input Data Set of Statistics](#)” on page 9920.

### **DIST=LOGNORMAL | NORMAL**

specifies the underlying distribution assumed for the data. You can specify the following values:

<b>LOGNORMAL</b>	specifies that the underlying distribution is lognormal.
<b>NORMAL</b>	specifies that the underlying distribution is normal.

By default, **DIST=NORMAL**, unless **TEST=RATIO** is specified, in which case the default is **DIST=LOGNORMAL**.

### **H0=m**

requests tests against a null value of  $m$ , unless the **TOST** option is used, in which case  $m$  is merely used to derive the lower and upper equivalence bounds. For the crossover design, the value  $m$  applies for both treatment and period tests. By default,  $H_0=0$  when **TEST=DIFF** (or **DIST=NORMAL** for a one-sample design) and  $H_0=1$  when **TEST=RATIO** (or **DIST=LOGNORMAL** for a one-sample design).

**NOBYVAR**

includes all variables that are specified in the **PAIRED** or **VAR** statement together in each output table. If the **NOBYVAR** option is not specified, then the **BYVAR** option is enabled, grouping the results by the **PAIRED** and **VAR** variables.

**ORDER=DATA | FORMATTED | FREQ | INTERNAL | MIXED**

specifies the order in which to sort the levels of the classification variables (which are specified in the **CLASS** statement) and treatment variables (which are specified in the **CROSSOVER=** option in the **VAR** statement).

This option applies to the levels for all classification or treatment variables, except when you use the **ORDER=FORMATTED** option with numeric classification or treatment variables that have no explicit format. With this option, the levels of such variables are ordered by their internal value.

You can specify the following values:

Value of ORDER=	Levels Sorted By
<b>DATA</b>	Order of appearance in the input data set.
<b>FORMATTED</b>	External formatted value, except for numeric variables that have no explicit format, which are sorted by their unformatted (internal) value. The sort order is machine-dependent.
<b>FREQ</b>	Descending frequency count; levels that have the greatest number of observations come first in the order. In the event of a tie, <b>ORDER=MIXED</b> is used.
<b>INTERNAL</b> <b>MIXED</b>	Unformatted value. The sort order is machine-dependent. Same as <b>ORDER=FORMATTED</b> if the unformatted variable is character-valued; same as <b>ORDER=INTERNAL</b> otherwise (the unformatted variable is numeric-valued).

For **FORMATTED** and **INTERNAL**, the sort order is machine-dependent.

For more information about sort order, see the chapter on the **SORT** procedure in the *Base SAS Procedures Guide* and the discussion of BY-group processing in *SAS Language Reference: Concepts*.

By default, **ORDER=MIXED**, which corresponds to the ordering in releases previous to SAS 9.2.

**PLOTS** <(global-plot-options)> <= plot-request<(options)>>

**PLOTS** <(global-plot-options)> <= (plot-request<(options)> <... plot-request<(options)>>>

controls the plots produced through ODS Graphics. When you specify only one *plot-request*, you can omit the parentheses around the *plot-request*. Here are some examples:

```
plots=none
plots=(histogram boxplot interval qq profiles agreement)
plots(unpack)=summary
plots(showh0)=interval(type=pergroup)
plots=(summary(unpack) interval(type=period))
```

ODS Graphics must be enabled before plots can be requested. For example:

```
ods graphics on;

proc ttest plots=all;
    var oxygen;
run;

ods graphics off;
```

For more information about enabling and disabling ODS Graphics, see the section “[Enabling and Disabling ODS Graphics](#)” on page 607 in Chapter 21, “[Statistical Graphics Using ODS](#).”

If ODS Graphics is enabled but you do not specify the [PLOTS](#) option, then PROC TTEST produces a default set of plots. (**NOTE:** The graphical results are unavailable if your input data set contains summary statistics rather than observation values.)

For a one-sample design, the default plots are the following:

- summary plot (histogram with overlaid normal and kernel densities, box plot, and confidence interval band)
- Q-Q plot

For a two-independent-sample design, the default plots are the following:

- summary plot (comparative histograms with overlaid densities and box plots)
- Q-Q plot

For a paired design, the default plots are the following:

- summary plot (histogram, densities, box plot, and confidence interval) of the difference or ratio
- Q-Q plot of the difference or ratio
- profiles plot
- agreement plot

For a crossover design, the default plots are the following:

- comparative histograms with overlaid densities by treatment and period
- comparative box plots by treatment and period
- Q-Q plots by treatment and period
- profiles over treatment plot
- agreement of treatments plot

For more detailed descriptions of plots, see the section “[Interpreting Graphs](#)” on page 9937.

You can specify the following *global-plot-options*:

**ONLY**

suppresses the default plots. Only plots that are specifically requested are displayed.

**SHOWHO****SHOWNULL**

shows the null value (as specified by the **H0=** option in the **PROC TTEST** statement) in all relevant plots. For one-sample and paired designs, the null value can appear when you also specify the **SUMMARY**, **BOX**, or **INTERVAL** *plot-request*. For two-independent-sample and crossover designs, the null value can appear only when you specify the **INTERVAL** *plot-request*.

**UNPACKPANEL****UNPACK**

suppresses paneling. By default, multiple plots can appear in some output panels. Specify **UNPACKPANEL** to get each plot in a separate panel. You can specify **PLOTS(UNPACKPANEL)** to unpack the default plots.

You can specify the following *plot-requests*:

**ALL**

produces all appropriate plots. You can specify other *plot-requests* with **ALL**; for example, to request all plots and specify that intervals should be for the period difference in a crossover design, specify **PLOTS=(ALL INTERVAL(TYPE=PERIOD))**.

**AGREEMENT < TYPE=type >****AGREEMENTPLOT < TYPE=type >**

requests an agreement plot. This plot is produced by default for paired and crossover designs, the only designs for which the **AGREEMENT** option is valid.

For paired designs, the second response in each pair is plotted against the first response. For more information, see the section “[Agreement Plots for Paired Designs](#)” on page 9937.

For crossover designs, you can specify the following options:

**TYPE=PERIOD**

plots the response in the second period against the response in the first period. For more information, see the section “[Period Agreement Plots for Crossover Designs](#)” on page 9938.

**TYPE=TREATMENT**

plots the response associated with the second treatment against the response associated with the first treatment. For more information, see the section “[Treatment Agreement Plots for Crossover Designs](#)” on page 9938.

By default, **TYPE=TREATMENT** for crossover designs.

**BOX****BOXPLOT**

requests a box plot or comparative box plots. A box plot is produced by default for crossover designs. For other designs, a box plot appears by default if you specify the **SUMMARY** or **ALL** *plot-request*.



For one-sample and paired designs, a confidence interval for the mean is shown as a band in the background, along with the equivalence bounds if the **TOST** option is used in the **PROC TTEST** statement.

For a two-independent-sample design, comparative box plots (one for each class) are shown. For a crossover design, comparative box plots for all four combinations of the two treatments and two periods are shown.

For more information, see the section “**Box Plots**” on page 9938.

## HISTOGRAM

### HIST

### HISTDENS

requests a histogram or comparative histograms along with overlaid normal and kernel densities. A histogram is produced by default for crossover designs. For other designs, it appears by default if you specify the **SUMMARY** or **ALL plot-request**.

For one-sample and paired designs, the histogram and densities are based on the test criterion (which is the mean difference or ratio for a paired design). For a two-independent-sample design, comparative histograms (one for each class) are shown. For a crossover design, histograms for all four combinations of the two treatments and two periods are shown.

For more information, see the section “**Histograms**” on page 9938.

### INTERVAL < TYPE=type >

### INTERVALPLOT < TYPE=type >

requests plots of confidence interval for means.

For a two-independent-sample design, you can specify one of the following options:

#### TYPE=PERGROUP

shows two separate two-sided confidence intervals, one for each class. This option cannot be used along with the **SHOWH0** global plot option.

#### TYPE=TEST

shows pooled and Satterthwaite confidence intervals.

By default, **TYPE=TEST** for two-independent-sample designs.

For a crossover design, you can specify the following options:

#### TYPE=PERGROUP

shows four separate two-sided intervals, one for each treatment-by-period combination. This option cannot be used along with the **SHOWH0** global plot option.

#### TYPE=PERIOD

shows pooled and Satterthwaite confidence intervals for the period difference or ratio. This option is invalid if the **IGNOREPERIOD** option is used in the **VAR** statement.

#### TYPE=TREATMENT

shows pooled and Satterthwaite confidence intervals for the treatment difference or ratio.

By default, **TYPE=TREATMENT** for crossover designs.

For more information, see the section “**Confidence Intervals**” on page 9938.

**NONE**

suppresses all plots.

**PROFILES < TYPE=type >****PROFILESPLOT < TYPE=type >**

requests a profiles plot. This plot is produced by default for paired and crossover designs, the only designs for which the **PROFILES** option is valid.

For paired designs, a line is drawn for each observation from left to right connecting the first response to the second response. For more information, see the section “[Profiles for Paired Designs](#)” on page 9939.

For crossover designs, you can specify one of the following options:

**TYPE=PERIOD**

shows response profiles over period, connecting the first period on the left to the second period on the right for each subject. For more information, see the section “[Profiles over Period for Crossover Designs](#)” on page 9939.

**TYPE=TREATMENT**

shows response profiles over treatment values, connecting the first treatment on the left to the second treatment on the right for each observation. For more information, see the section “[Profiles over Treatment for Crossover Designs](#)” on page 9939.

By default, TYPE=TREATMENT for crossover designs.

**QQ****QQPLOT**

requests a normal quantile-quantile (Q-Q) plot. This plot is produced by default for all designs.

For two-sample designs, separate plots are shown for each class in a single panel. For crossover design, separate plots are shown for each treatment-by-period combination in a single panel.

For more information, see the section “[Q-Q Plots](#)” on page 9939.

**SUMMARY < UNPACK >****SUMMARYPLOT < UNPACK >**

requests **HISTOGRAM** and **BOX** plots together in a single panel, sharing common X axes. These plots are produced by default for one-sample, paired, and two-independent-sample designs, the only designs for which the **SUMMARY** option is valid. For more information, see the documentation for the **BOX** and **HISTOGRAM** *plot-requests*. You can specify the following option:

**UNPACK**

plots histograms along with overlaid densities in one panel and box plots (along with confidence interval bands, if one-sample or paired design) in another. Note that specifying **PLOTS(ONLY)=SUMMARY(UNPACK)** is exactly the same as specifying **PLOTS(ONLY)=(BOX HISTOGRAM)**.

**SIDES=2 | L | U****SIDED=2 | L | U****SIDE=2 | L | U**

specifies the number of sides (or tails) and direction of the statistical tests and test-based confidence intervals. The values are interpreted as follows:

<b>2</b>	specifies two-sided tests and confidence intervals for means.
<b>L</b>	specifies lower one-sided tests (in which the alternative hypothesis indicates a mean less than the null value) and lower one-sided confidence intervals between minus infinity and the upper confidence limit.
<b>U</b>	specifies upper one-sided tests (in which the alternative hypothesis indicates a mean greater than the null value) and upper one-sided confidence intervals between the lower confidence limit and infinity.

By default, SIDES=2.

**TEST=DIFF | RATIO**

specifies the test criterion. This option is ignored for one-sample designs. You can specify the following values:

<b>DIFF</b>	tests the difference of means.
<b>RATIO</b>	tests the ratio of means.

By default, TEST=DIFF, unless **DIST=LOGNORMAL** is specified, in which case the default is TEST=RATIO.

**TOST ( < lower , > upper )**

requests Schuirmann's TOST equivalence test. The *upper* equivalence bound must be specified. If **TEST=DIFF**, then the default value for the *lower* equivalence bound is  $2m - upper$ , where  $m$  is the value of the **H0=** option. If **TEST=RATIO**, then the default value for *lower* is  $m / upper$ .

---

## BY Statement

**BY variables ;**

You can specify a BY statement with PROC TTEST to obtain separate analyses of observations in groups that are defined by the BY variables. When a BY statement appears, the procedure expects the input data set to be sorted in order of the BY variables. If you specify more than one BY statement, only the last one specified is used.

If your input data set is not sorted in ascending order, use one of the following alternatives:

- Sort the data by using the SORT procedure with a similar BY statement.
- Specify the NOTSORTED or DESCENDING option in the BY statement for the TTEST procedure. The NOTSORTED option does not mean that the data are unsorted but rather that the data are arranged in groups (according to values of the BY variables) and that these groups are not necessarily in alphabetical or increasing numeric order.

- Create an index on the BY variables by using the DATASETS procedure (in Base SAS software).

For more information about BY-group processing, see the discussion in *SAS Language Reference: Concepts*.  
For more information about the DATASETS procedure, see the discussion in the *Base SAS Procedures Guide*.

---

## CLASS Statement

**CLASS** *variable* ;

A **CLASS** statement giving the name of the classification (or grouping) variable must accompany the **PROC TTEST** statement in the two-independent-sample case. It should be omitted for the one-sample, paired, and AB/BA crossover designs. If it is used without the **VAR** statement, all numeric variables in the input data set (except those that appear in the **CLASS**, **BY**, **FREQ**, or **WEIGHT** statement) are included in the analysis.

The classification variable must have two, and only two, levels. PROC TTEST divides the observations into the two groups for the *t* test by using the levels of this variable. You can use either a numeric or a character variable in the **CLASS** statement.

Classification levels are determined from the formatted values of the **CLASS** variable. Thus, you can use formats to define group levels. For more information, see the discussions of the **FORMAT** procedure, the **FORMAT** statement, formats, and informats in *SAS Formats and Informats: Reference*.

---

## FREQ Statement

**FREQ** *variable* ;

The *variable* in the **FREQ** statement identifies a variable that contains the frequency of occurrence of each observation. PROC TTEST treats each observation as if it appears *n* times, where *n* is the value of the **FREQ** variable for the observation. If the value is not an integer, only the integer portion is used. If the frequency value is less than 1 or is missing, the observation is not used in the analysis. When the **FREQ** statement is not specified, each observation is assigned a frequency of 1. The **FREQ** statement cannot be used if the **DATA=** data set contains statistics instead of the original observations.

---

## PAIRED Statement

**PAIRED** *pair-lists* ;

The *pair-lists* in the **PAIRED** statement identifies the variables to be compared in paired comparisons. You can use one or more *pair-lists*. Variables or lists of variables are separated by an asterisk (\*) or a colon (:). The asterisk requests that each variable on the left be compared with each variable on the right. The colon requests that the first variable on the left be compared with the first on the right, the second on the left with the second on the right, and so on. The number of variables on the left must equal the number on the right when the colon is used. The differences are calculated by taking the variable on the left minus the variable on the right for both the asterisk and colon. A pair that is formed by a variable with itself is ignored. Use the **PAIRED** statement only for paired comparisons. The **CLASS** and **VAR** statements cannot be used with the **PAIRED** statement.

Examples of the use of the asterisk and the colon are shown in Table 121.3.

**Table 121.3** PAIRED Statement in the TTEST Procedure

These PAIRED Statements	Yield These Comparisons
<b>PAIRED</b> A*B;	A-B
<b>PAIRED</b> A*B C*D;	A-B and C-D
<b>PAIRED</b> (A B) * (C D) ;	A-C, A-D, B-C, and B-D
<b>PAIRED</b> (A B) * (C B) ;	A-C, A-B, and B-C
<b>PAIRED</b> (A1-A2) * (B1-B2) ;	A1-B1, A1-B2, A2-B1, and A2-B2
<b>PAIRED</b> (A1-A2) : (B1-B2) ;	A1-B1 and A2-B2

## VAR Statement

**VAR** *variables* </ options> ;

The **VAR** statement names the variables to be used in the analyses. One-sample comparisons are conducted when the **VAR** statement is used without the **CROSSOVER=** option or **CLASS** statement. Two-independent-sample comparisons are conducted when the **VAR** statement is used with a **CLASS** statement.

An AB/BA crossover analysis is conducted when the **CROSSOVER=** option is used in the **VAR** statement. In this case, you must specify an even number of variables. Each set of two variables represents the responses in the first and second periods of the AB/BA crossover design. For example, if you use the **CROSSOVER=** option and specify **VAR x1 x2 x3 x4**, then you will get two analyses. One analysis will have x1 as the period 1 response and x2 as the period 2 response. The other analysis will have x3 as the period 1 response and x4 as the period 2 response.

The **VAR** statement cannot be used with the **PAIRED** statement. If the **VAR** statement is omitted, all numeric variables in the input data set (except a numeric variable that appears in the **BY**, **CLASS**, **FREQ**, or **WEIGHT** statement) are included in the analysis.

You can specify the following *options* after a slash (/):

### **CROSSOVER=** ( *variable1 variable2* )

specifies the variables that represent the treatment applied in each of the two periods in an AB/BA crossover design. The treatment variables must have two, and only two, levels. For any particular observation, the levels for the two variables must be different, due to the restrictions of the AB/BA crossover design. You can use either numeric or character variables.

Treatment levels are determined from the formatted values of the variables. Thus, you can use formats to define the treatment levels. For more information, see the discussions of the **FORMAT** procedure, the **FORMAT** statement, formats, and informats in *SAS Formats and Informats: Reference*.

### **IGNOREPERIOD**

ignores the period effect—that is, the period effect is assumed to be equal to 0 (if **TEST=DIFF**) or 1 (if **TEST=RATIO**). This assumption increases the degrees of freedom for the test of the treatment

difference by 1 and is usually more powerful, but it risks incorrect results if there is actually a period effect.

---

## WEIGHT Statement

**WEIGHT** *variable* ;

The **WEIGHT** statement weights each observation in the input data set by the value of the *variable*. The values of the *variable* can be nonintegral, and they are not truncated. Observations that have negative, zero, or missing values for the *variable* are not used in the analyses. Each observation is assigned a weight of 1 when the **WEIGHT** statement is not used. The **WEIGHT** statement cannot be used with an input data set of summary statistics.

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## Details: TTEST Procedure

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### Input Data Set of Statistics

PROC TTEST accepts data containing either observation values or summary statistics. Observation values are supported for all analyses, whereas summary statistics are supported only for a subset of analyses. If the analysis involves the paired design, the AB/BA crossover design, or the lognormal distributional assumption (**DIST=LOGNORMAL**), then observation values must be used. The graphical results are unavailable if your input data set contains summary statistics rather than raw observed values.

PROC TTEST assumes that the **DATA=** data set contains statistics if it contains a character variable with name **\_TYPE\_** or **\_STAT\_**. The TTEST procedure expects this character variable to contain the names of statistics. If both **\_TYPE\_** and **\_STAT\_** variables exist and are of type character, PROC TTEST expects **\_TYPE\_** to contain the names of statistics including 'N', 'MEAN', and 'STD' for each **BY** group (or for each class within each **BY** group for two-sample *t* tests). If no 'N', 'MEAN', or 'STD' statistics exist, an error message is printed.

**FREQ**, **WEIGHT**, and **PAIRED** statements cannot be used with input data sets of statistics. **BY**, **CLASS**, and **VAR** statements are the same regardless of data set type. For paired comparisons, see the **\_DIF\_** values for the **\_TYPE\_=T** observations in output produced by the **OUTSTATS=** option in the PROC COMPARE statement (see the *Base SAS Procedures Guide*).

---

### Missing Values

An observation is omitted from the calculations if it has a missing value for either the **CLASS** variable, a **CROSSOVER=** variable, a **PAIRED** variable, the variable to be tested (in a one-sample or two-independent-sample design), or either of the two response variables (in a crossover design). If more than one variable or pair of variables is listed in the **VAR** statement, a missing value in one variable or pair does not eliminate the observation from the analysis of other nonmissing variables or variable pairs.

## Computational Methods

This section describes the computational formulas for the estimates, confidence limits, and tests for each analysis in the TTEST procedure. The first subsection defines some common notation. The second subsection discusses the distinction between arithmetic and geometric means. The third subsection explains the concept of the coefficient of variation. The following four subsections address the four supported designs (one-sample, paired, two-independent-sample, and AB/BA crossover). The content in each of those subsections is divided into separate discussions according to different values of the **DIST=** and **TEST=** options in the **PROC TTEST** statement. The last subsection describes TOST equivalence analyses.

### Common Notation

Table 121.4 displays notation for some of the commonly used symbols.

**Table 121.4** Common Notation

Symbol	Description
$\mu$	Population value of (arithmetic) mean
$\mu_0$	Null value of test (value of <b>H0=</b> option in <b>PROC TTEST</b> statement)
$\sigma^2$	Population variance
$\sigma$	Population value of standard deviation
$\gamma$	Population value of geometric mean
CV	Population value of coefficient of variation (ratio of population standard deviation and population arithmetic mean)
$\alpha$	Value of <b>ALPHA=</b> option in <b>PROC TTEST</b> statement
$t_{p,v}$	$p$ th percentile of $t$ distribution with $v$ degrees of freedom ( $df$ )
$F_{p,v_1,v_2}$	$p$ th percentile of $F$ distribution with $v_1$ numerator $df$ and $v_2$ denominator $df$
$\chi^2_{p,v}$	$p$ th percentile of chi-square distribution with $v$ $df$

### Arithmetic and Geometric Means

The *arithmetic mean* (more commonly called simply the *mean*) of the distribution of a random variable  $X$  is its expected value,  $E(X)$ . The arithmetic mean is the natural parameter of interest for a normal distribution because the distribution of the difference of normal random variables has a known normal distribution, and the arithmetic mean of a normal difference is equal to the difference of the individual arithmetic means. (No such convenient property holds for geometric means with normal data, with either differences or ratios.)

The usual estimate of an arithmetic mean is the sum of the values divided by the number of values:

$$\text{arithmetic mean} = \frac{1}{n} \sum_{i=1}^n y_i$$

The *geometric mean* of the distribution of a random variable  $X$  is  $\exp(E(\log(X)))$ , the exponentiation of the mean of the natural logarithm. The geometric mean is the natural parameter of interest for a lognormal distribution because the distribution of a ratio of lognormal random variables has a known lognormal distribution, and the geometric mean of a lognormal ratio is equal to the ratio of the individual geometric means. (No such convenient property holds for arithmetic means with lognormal data, with either differences or ratios.)

The usual estimate of a geometric mean is the product of the values raised to the power  $1/n$ , where  $n$  is the number of values:

$$\text{geometric mean} = \left( \prod_{i=1}^n y_i \right)^{\frac{1}{n}}$$

### Coefficient of Variation

The *coefficient of variation* (abbreviated “CV”) of the distribution of a random variable  $X$  is the ratio of the standard deviation to the (arithmetic) mean, or  $\sqrt{\text{Var}(X)}/E(X)$ . Conceptually, it is a measure of the variability of  $X$  expressed in units corresponding to the mean of  $X$ .

For lognormal data, the CV is the natural measure of variability (rather than the standard deviation) because the CV is invariant to multiplication of a lognormal variable by a constant. For a two-independent-sample design, the assumption of equal CVs on a lognormal scale is analogous to the assumption of equal variances on the normal scale. When the CVs of two independent samples of lognormal data are assumed equal, the pooled estimate of variability is used.

### One-Sample Design

Define the following notation:

$n^*$  = number of observations in data set

$y_i$  = value of  $i$ th observation,  $i \in \{1, \dots, n^*\}$

$f_i$  = frequency of  $i$ th observation,  $i \in \{1, \dots, n^*\}$

$w_i$  = weight of  $i$ th observation,  $i \in \{1, \dots, n^*\}$

$$n = \text{sample size} = \sum_i^{n^*} f_i$$

#### Normal Data (DIST=NORMAL)

The mean estimate  $\bar{y}$ , standard deviation estimate  $s$ , and standard error SE are computed as follows:

$$\begin{aligned} \bar{y} &= \frac{\sum_i^{n^*} f_i w_i y_i}{\sum_i^{n^*} f_i w_i} \\ s &= \left( \frac{\sum_i^{n^*} f_i w_i (y_i - \bar{y})^2}{n - 1} \right)^{\frac{1}{2}} \\ \text{SE} &= \frac{s}{\sum_i^{n^*} f_i w_i} \end{aligned}$$



The  $100(1 - \alpha)\%$  confidence interval for the mean  $\mu$  is

$$\begin{aligned} & \left( \bar{y} - t_{1-\frac{\alpha}{2}, n-1} \text{SE} , \bar{y} + t_{1-\frac{\alpha}{2}, n-1} \text{SE} \right), \text{ SIDES}=2 \\ & \left( -\infty , \bar{y} + t_{1-\alpha, n-1} \text{SE} \right), \text{ SIDES}=L \\ & \left( \bar{y} - t_{1-\alpha, n-1} \text{SE} , \infty \right), \text{ SIDES}=U \end{aligned}$$

The  $t$  value for the test is computed as

$$t = \frac{\bar{y} - \mu_0}{\text{SE}}$$

The  $p$ -value of the test is computed as

$$p\text{-value} = \begin{cases} P(t^2 > F_{1-\alpha, 1, n-1}) & , \text{ 2-sided} \\ P(t < t_{\alpha, n-1}) & , \text{ lower 1-sided} \\ P(t > t_{1-\alpha, n-1}) & , \text{ upper 1-sided} \end{cases}$$

The equal-tailed confidence interval for the standard deviation (**CI=EQUAL**) is based on the acceptance region of the test of  $H_0: \sigma = \sigma_0$  that places an equal amount of area ( $\frac{\alpha}{2}$ ) in each tail of the chi-square distribution:

$$\left\{ \chi_{\frac{\alpha}{2}, n-1}^2 \leq \frac{(n-1)s^2}{\sigma_0^2} \leq \chi_{\frac{1-\alpha}{2}, n-1}^2 \right\}$$

The acceptance region can be algebraically manipulated to give the following  $100(1 - \alpha)\%$  confidence interval for  $\sigma^2$ :

$$\left( \frac{(n-1)s^2}{\chi_{1-\frac{\alpha}{2}, n-1}^2} , \frac{(n-1)s^2}{\chi_{\frac{\alpha}{2}, n-1}^2} \right)$$

Taking the square root of each side yields the  $100(1 - \alpha)\%$  **CI=EQUAL** confidence interval for  $\sigma$ :

$$\left( \left( \frac{(n-1)s^2}{\chi_{1-\frac{\alpha}{2}, n-1}^2} \right)^{\frac{1}{2}} , \left( \frac{(n-1)s^2}{\chi_{\frac{\alpha}{2}, n-1}^2} \right)^{\frac{1}{2}} \right)$$

The other confidence interval for the standard deviation (**CI=UMPU**) is derived from the uniformly most powerful unbiased test of  $H_0: \sigma = \sigma_0$  (Lehmann 1986). This test has acceptance region

$$\left\{ c_1 \leq \frac{(n-1)s^2}{\sigma_0^2} \leq c_2 \right\}$$

where the critical values  $c_1$  and  $c_2$  satisfy

$$\int_{c_1}^{c_2} f_{n-1}(y) dy = 1 - \alpha$$

and

$$\int_{c_1}^{c_2} y f_{n-1}(y) dy = (n-1)(1 - \alpha)$$

where  $f_v(y)$  is the PDF of the chi-square distribution with  $v$  degrees of freedom. This acceptance region can be algebraically manipulated to arrive at

$$P \left\{ \frac{(n-1)s^2}{c_2} \leq \sigma^2 \leq \frac{(n-1)s^2}{c_1} \right\} = 1 - \alpha$$

where  $c_1$  and  $c_2$  solve the preceding two integrals. To find the area in each tail of the chi-square distribution to which these two critical values correspond, solve  $c_1 = \chi_{1-\alpha_2, n-1}^2$  and  $c_2 = \chi_{\alpha_1, n-1}^2$  for  $\alpha_1$  and  $\alpha_2$ ; the resulting  $\alpha_1$  and  $\alpha_2$  sum to  $\alpha$ . Hence, a  $100(1 - \alpha)\%$  confidence interval for  $\sigma^2$  is given by

$$\left( \frac{(n-1)s^2}{\chi_{1-\alpha_2, n-1}^2}, \frac{(n-1)s^2}{\chi_{\alpha_1, n-1}^2} \right)$$

Taking the square root of each side yields the  $100(1 - \alpha)\%$  **CI=UMPU** confidence interval for  $\sigma$ :

$$\left( \left( \frac{(n-1)s^2}{\chi_{1-\alpha_2, n-1}^2} \right)^{\frac{1}{2}}, \left( \frac{(n-1)s^2}{\chi_{\alpha_1, n-1}^2} \right)^{\frac{1}{2}} \right)$$

### **Lognormal Data (DIST=LOGNORMAL)**

The **DIST=LOGNORMAL** analysis is handled by log-transforming the data and null value, performing a **DIST=NORMAL** analysis, and then transforming the results back to the original scale. This simple technique is based on the properties of the lognormal distribution as discussed in Johnson, Kotz, and Balakrishnan (1994, Chapter 14).

Taking the natural logarithms of the observation values and the null value, define

$$z_i = \log(y_i) \quad , \quad i \in \{1, \dots, n^*\}$$

$$\gamma_0 = \log(\mu_0)$$

First, a **DIST=NORMAL** analysis is performed on  $\{z_i\}$  with the null value  $\gamma_0$ , producing the mean estimate  $\bar{z}$ , the standard deviation estimate  $s_z$ , a  $t$  value, and a  $p$ -value. The geometric mean estimate  $\hat{\gamma}$  and the CV estimate  $\widehat{CV}$  of the original lognormal data are computed as follows:

$$\hat{\gamma} = \exp(\bar{z})$$

$$\widehat{CV} = (\exp(s_z^2) - 1)^{\frac{1}{2}}$$

The  $t$  value and  $p$ -value remain the same. The confidence limits for the geometric mean and CV on the original lognormal scale are computed from the confidence limits for the arithmetic mean and standard deviation in the **DIST=NORMAL** analysis on the log-transformed data, in the same way that  $\hat{\gamma}$  is derived from  $\bar{z}$  and  $\widehat{CV}$  is derived from  $s_z$ .

## Paired Design

Define the following notation:

$n^*$  = number of observations in data set

$y_{1i}$  = value of  $i$ th observation for first PAIRED variable,  $i \in \{1, \dots, n^*\}$

$y_{2i}$  = value of  $i$ th observation for second PAIRED variable,  $i \in \{1, \dots, n^*\}$

$f_i$  = frequency of  $i$ th observation,  $i \in \{1, \dots, n^*\}$

$w_i$  = weight of  $i$ th observation,  $i \in \{1, \dots, n^*\}$

$$n = \text{sample size} = \sum_i^{n^*} f_i$$

### **Normal Difference (DIST=NORMAL TEST=DIFF)**

The analysis is the same as the analysis for the one-sample design in the section “Normal Data (DIST=NORMAL)” on page 9922 based on the differences

$$d_i = y_{1i} - y_{2i} \quad , \quad i \in \{1, \dots, n^*\}$$

### **Lognormal Ratio (DIST=LOGNORMAL TEST=RATIO)**

The analysis is the same as the analysis for the one-sample design in the section “Lognormal Data (DIST=LOGNORMAL)” on page 9924 based on the ratios

$$r_i = y_{1i}/y_{2i} \quad , \quad i \in \{1, \dots, n^*\}$$

### **Normal Ratio (DIST=NORMAL TEST=RATIO)**

The hypothesis  $H_0: \mu_1/\mu_2 = \mu_0$ , where  $\mu_1$  and  $\mu_2$  are the means of the first and second PAIRED variables, respectively, can be rewritten as  $H_0: \mu_1 - \mu_0\mu_2 = 0$ . The  $t$  value and  $p$ -value are computed in the same way as in the one-sample design in the section “Normal Data (DIST=NORMAL)” on page 9922 based on the transformed values

$$z_i = y_{1i} - \mu_0 y_{2i} \quad , \quad i \in \{1, \dots, n^*\}$$

Estimates and confidence limits are not computed for this situation.

## Two-Independent-Sample Design

Define the following notation:

$$\begin{aligned}
 n_1^* &= \text{number of observations at first class level} \\
 n_2^* &= \text{number of observations at second class level} \\
 y_{1i} &= \text{value of } i\text{th observation at first class level, } i \in \{1, \dots, n_1^*\} \\
 y_{2i} &= \text{value of } i\text{th observation at second class level, } i \in \{1, \dots, n_2^*\} \\
 f_{1i} &= \text{frequency of } i\text{th observation at first class level, } i \in \{1, \dots, n_1^*\} \\
 f_{2i} &= \text{frequency of } i\text{th observation at second class level, } i \in \{1, \dots, n_2^*\} \\
 w_{1i} &= \text{weight of } i\text{th observation at first class level, } i \in \{1, \dots, n_1^*\} \\
 w_{2i} &= \text{weight of } i\text{th observation at second class level, } i \in \{1, \dots, n_2^*\} \\
 n_1 &= \text{sample size for first class level} = \sum_i^{n_1^*} f_{1i} \\
 n_2 &= \text{sample size for second class level} = \sum_i^{n_2^*} f_{2i}
 \end{aligned}$$

### Normal Difference (DIST=NORMAL TEST=DIFF)

Observations at the first class level are assumed to be distributed as  $N(\mu_1, \sigma_1^2)$ , and observations at the second class level are assumed to be distributed as  $N(\mu_2, \sigma_2^2)$ , where  $\mu_1$ ,  $\mu_2$ ,  $\sigma_1$ , and  $\sigma_2$  are unknown.

The within-class-level mean estimates ( $\bar{y}_1$  and  $\bar{y}_2$ ), standard deviation estimates ( $s_1$  and  $s_2$ ), standard errors ( $SE_1$  and  $SE_2$ ), and confidence limits for means and standard deviations are computed in the same way as for the one-sample design in the section “Normal Data (DIST=NORMAL)” on page 9922.

The mean difference  $\mu_1 - \mu_2 = \mu_d$  is estimated by

$$\bar{y}_d = \bar{y}_1 - \bar{y}_2$$

Under the assumption of equal variances ( $\sigma_1^2 = \sigma_2^2$ ), the pooled estimate of the common standard deviation is

$$s_p = \left( \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \right)^{\frac{1}{2}}$$

The pooled standard error (the estimated standard deviation of  $\bar{y}_d$  assuming equal variances) is

$$SE_p = s_p \left( \frac{1}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{1}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^{\frac{1}{2}}$$

The pooled  $100(1 - \alpha)\%$  confidence interval for the mean difference  $\mu_d$  is

$$\begin{aligned}
 &(\bar{y}_d - t_{1-\frac{\alpha}{2}, n_1+n_2-2} SE_p, \bar{y}_d + t_{1-\frac{\alpha}{2}, n_1+n_2-2} SE_p), \text{ SIDES=2} \\
 &(-\infty, \bar{y}_d + t_{1-\alpha, n_1+n_2-2} SE_p), \text{ SIDES=L} \\
 &(\bar{y}_d - t_{1-\alpha, n_1+n_2-2} SE_p, \infty), \text{ SIDES=U}
 \end{aligned}$$

The  $t$  value for the pooled test is computed as

$$t_p = \frac{\bar{y}_d - \mu_0}{SE_p}$$

The  $p$ -value of the test is computed as

$$p\text{-value} = \begin{cases} P(t_p^2 > F_{1-\alpha, 1, n_1+n_2-2}) & , \quad 2\text{-sided} \\ P(t_p < t_{\alpha, n_1+n_2-2}) & , \quad \text{lower 1-sided} \\ P(t_p > t_{1-\alpha, n_1+n_2-2}) & , \quad \text{upper 1-sided} \end{cases}$$

Under the assumption of unequal variances (the Behrens-Fisher problem), the unpooled standard error is computed as

$$SE_u = \left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^{\frac{1}{2}}$$

Satterthwaite's (1946) approximation for the degrees of freedom, extended to accommodate weights, is computed as

$$df_u = \frac{SE_u^4}{\frac{s_1^4}{(n_1-1)\left(\sum_{i=1}^{n_1^*} f_{1i} w_{1i}\right)^2} + \frac{s_2^4}{(n_2-1)\left(\sum_{i=1}^{n_2^*} f_{2i} w_{2i}\right)^2}}$$

The unpooled Satterthwaite  $100(1-\alpha)\%$  confidence interval for the mean difference  $\mu_d$  is

$$\begin{aligned} & \left( \bar{y}_d - t_{1-\frac{\alpha}{2}, df_u} SE_u, \bar{y}_d + t_{1-\frac{\alpha}{2}, df_u} SE_u \right), \text{ SIDES}=2 \\ & \left( -\infty, \bar{y}_d + t_{1-\alpha, df_u} SE_u \right), \text{ SIDES}=L \\ & \left( \bar{y}_d - t_{1-\alpha, df_u} SE_u, \infty \right), \text{ SIDES}=U \end{aligned}$$

The  $t$  value for the unpooled Satterthwaite test is computed as

$$t_u = \frac{\bar{y}_d - \mu_0}{SE_u}$$

The  $p$ -value of the unpooled Satterthwaite test is computed as

$$p\text{-value} = \begin{cases} P(t_u^2 > F_{1-\alpha, 1, df_u}) & , \quad 2\text{-sided} \\ P(t_u < t_{\alpha, df_u}) & , \quad \text{lower 1-sided} \\ P(t_u > t_{1-\alpha, df_u}) & , \quad \text{upper 1-sided} \end{cases}$$

When the **COCHRAN** option is specified in the **PROC TTEST** statement, the Cochran and Cox (1950) approximation of the  $p$ -value of the  $t_u$  statistic is the value of  $p$  such that

$$t_u = \frac{\left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} \right) t_1 + \left( \frac{s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right) t_2}{\left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} \right) + \left( \frac{s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)}$$

where  $t_1$  and  $t_2$  are the critical values of the  $t$  distribution corresponding to a significance level of  $p$  and sample sizes of  $n_1$  and  $n_2$ , respectively. The number of degrees of freedom is undefined when  $n_1 \neq n_2$ . In general, the Cochran and Cox test tends to be conservative (Lee and Gurland 1975).

The  $100(1 - \alpha)\%$  **CI=EQUAL** and **CI=UMPU** confidence intervals for the common population standard deviation  $\sigma$  assuming equal variances are computed as discussed in the section “**Normal Data (DIST=NORMAL)**” on page 9922 for the one-sample design, except replacing  $s^2$  by  $s_p^2$  and  $(n - 1)$  by  $(n_1 + n_2 - 1)$ .

The folded form of the  $F$  statistic,  $F'$ , tests the hypothesis that the variances are equal (Steel and Torrie 1980), where

$$F' = \frac{\max(s_1^2, s_2^2)}{\min(s_1^2, s_2^2)}$$

A test of  $F'$  is a two-tailed  $F$  test because you do not specify which variance you expect to be larger. The  $p$ -value (Steel and Torrie 1980) is equal-tailed and is computed as

$$\begin{aligned} p\text{-value} &= 2P(F' > F_{1-\alpha, df_a, df_b}) \\ &= \begin{cases} P(s_1^2/s_2^2 > F_{1-\alpha, df_1, df_2}) + P(s_2^2/s_1^2 \leq F_{1-\alpha, df_2, df_1}) & , \quad s_1^2/s_2^2 \geq 1 \\ P(s_1^2/s_2^2 \leq F_{1-\alpha, df_1, df_2}) + P(s_2^2/s_1^2 > F_{1-\alpha, df_2, df_1}) & , \quad s_1^2/s_2^2 < 1 \end{cases} \end{aligned}$$

where  $df_1$ ,  $df_2$ ,  $df_a$ , and  $df_b$  are the degrees of freedom that correspond to  $s_1^2$ ,  $s_2^2$ ,  $\max(s_1^2, s_2^2)$ , and  $\min(s_1^2, s_2^2)$ , respectively.

Note that the  $p$ -value is similar to the probability  $p^*$  of a greater  $F'$  value under the null hypothesis that  $\sigma_1^2 = \sigma_2^2$ ,

$$p^* = \begin{cases} P(s_1^2/s_2^2 > F_{1-\alpha, df_1, df_2}) + P(s_2^2/s_1^2 \leq F_{1-\alpha, df_1, df_2}) & , \quad s_1^2/s_2^2 \geq 1 \\ P(s_1^2/s_2^2 \leq F_{1-\alpha, df_1, df_2}) + P(s_2^2/s_1^2 > F_{1-\alpha, df_1, df_2}) & , \quad s_1^2/s_2^2 < 1 \end{cases}$$

The  $F'$  test is not very robust to violations of the assumption that the data are normally distributed, and thus it is not recommended without confidence in the normality assumption.

### **Lognormal Ratio (DIST=LOGNORMAL TEST=RATIO)**

The **DIST=LOGNORMAL** analysis is handled by log-transforming the data and null value, performing a **DIST=NORMAL** analysis, and then transforming the results back to the original scale. See the section “**Normal Data (DIST=NORMAL)**” on page 9922 for the one-sample design for details on how the **DIST=NORMAL** computations for means and standard deviations are transformed into the **DIST=LOGNORMAL** results for geometric means and CVs. As mentioned in the section “**Coefficient of Variation**” on page 9922, the assumption of equal CVs on the lognormal scale is analogous to the assumption of equal variances on the normal scale.

### **Normal Ratio (DIST=NORMAL TEST=RATIO)**

The distributional assumptions, equality of variances test, and within-class-level mean estimates ( $\bar{y}_1$  and  $\bar{y}_2$ ), standard deviation estimates ( $s_1$  and  $s_2$ ), standard errors ( $SE_1$  and  $SE_2$ ), and confidence limits for means and standard deviations are the same as in the section “**Normal Difference (DIST=NORMAL TEST=DIFF)**” on page 9926 for the two-independent-sample design.

The mean ratio  $\mu_1/\mu_2 = \mu_r$  is estimated by

$$\hat{\mu}_r = \bar{y}_1/\bar{y}_2$$

No estimates or confidence intervals for the ratio of standard deviations are computed.

Under the assumption of equal variances ( $\sigma_1^2 = \sigma_2^2$ ), the pooled confidence interval for the mean ratio is the Fieller (1954) confidence interval, extended to accommodate weights. Let

$$\begin{aligned} a_p &= \frac{s_p^2 t_{1-\frac{\alpha}{2}, n_1+n_2-2}^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} - \bar{y}_2^2 \\ b_p &= \bar{y}_1 \bar{y}_2 \\ c_p &= \frac{s_p^2 t_{1-\frac{\alpha}{2}, n_1+n_2-2}^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} - \bar{y}_1^2 \end{aligned}$$

where  $s_p$  is the pooled standard deviation defined in the section “**Normal Difference (DIST=NORMAL TEST=DIFF)**” on page 9926 for the two-independent-sample design. If  $a_p \geq 0$  (which occurs when  $\bar{y}_2$  is too close to zero), then the pooled two-sided  $100(1 - \alpha)\%$  Fieller confidence interval for  $\mu_r$  does not exist. If  $a < 0$ , then the interval is

$$\left( -\frac{b_p}{a_p} + \frac{(b_p^2 - a_p c_p)^{\frac{1}{2}}}{a_p}, -\frac{b_p}{a_p} - \frac{(b_p^2 - a_p c_p)^{\frac{1}{2}}}{a_p} \right)$$

For the one-sided intervals, let

$$\begin{aligned} a_p^* &= \frac{s_p^2 t_{1-\alpha, n_1+n_2-2}^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} - \bar{y}_2^2 \\ c_p^* &= \frac{s_p^2 t_{1-\alpha, n_1+n_2-2}^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} - \bar{y}_1^2 \end{aligned}$$

which differ from  $a_p$  and  $c_p$  only in the use of  $\alpha$  in place of  $\alpha/2$ . If  $a_p^* \geq 0$ , then the pooled one-sided  $100(1 - \alpha)\%$  Fieller confidence intervals for  $\mu_r$  do not exist. If  $a_p^* < 0$ , then the intervals are

$$\begin{aligned} &\left( -\infty, -\frac{b_p}{a_p^*} - \frac{(b_p^2 - a_p^* c_p^*)^{\frac{1}{2}}}{a_p^*} \right), \text{ SIDES=L} \\ &\left( -\frac{b_p}{a_p^*} + \frac{(b_p^2 - a_p^* c_p^*)^{\frac{1}{2}}}{a_p^*}, \infty \right), \text{ SIDES=U} \end{aligned}$$

The pooled  $t$  test assuming equal variances is the Sasabuchi (1988a, b) test. The hypothesis  $H_0: \mu_r = \mu_0$  is rewritten as  $H_0: \mu_1 - \mu_0 \mu_2 = 0$ , and the pooled  $t$  test in the section “**Normal Difference (DIST=NORMAL TEST=DIFF)**” on page 9926 for the two-independent-sample design is conducted on the original  $y_{1i}$  values ( $i \in \{1, \dots, n_1^*\}$ ) and transformed values of  $y_{2i}$

$$y_{2i}^* = \mu_0 y_{2i}, \quad i \in \{1, \dots, n_2^*\}$$

with a null difference of 0. The  $t$  value for the Sasabuchi pooled test is computed as

$$t_p = \frac{\bar{y}_1 - \mu_0 \bar{y}_2}{s_p \left( \frac{1}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{\mu_0^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^{\frac{1}{2}}}$$

The  $p$ -value of the test is computed as

$$p\text{-value} = \begin{cases} P(t_p^2 > F_{1-\alpha, 1, n_1+n_2-2}) & , \quad 2\text{-sided} \\ P(t_p < t_{\alpha, n_1+n_2-2}) & , \quad \text{lower 1-sided} \\ P(t_p > t_{1-\alpha, n_1+n_2-2}) & , \quad \text{upper 1-sided} \end{cases}$$

Under the assumption of unequal variances, the unpooled Satterthwaite-based confidence interval for the mean ratio  $\mu_r$  is computed according to the method in Dilba, Schaarschmidt, and Hothorn (2007, the section “Two-sample Problem” on page 20), extended to accommodate weights. The degrees of freedom for the confidence interval are based on the same approximation as in Tamhane and Logan (2004) for the unpooled  $t$  test but with the null mean ratio  $\mu_0$  replaced by the maximum likelihood estimate  $\hat{\mu}_r = \bar{y}_1/\bar{y}_2$ :

$$\text{df}_u = \frac{\left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{\hat{\mu}_r^2 s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^2}{\frac{s_1^4}{(n_1-1) \left( \sum_{i=1}^{n_1^*} f_{1i} w_{1i} \right)^2} + \frac{\hat{\mu}_r^4 s_2^4}{(n_2-1) \left( \sum_{i=1}^{n_2^*} f_{2i} w_{2i} \right)^2}}$$

Let

$$\begin{aligned} a_u &= \frac{s_2^2 t_{1-\frac{\alpha}{2}, \text{df}_u}^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} - \bar{y}_2^2 \\ b_u &= \bar{y}_1 \bar{y}_2 \\ c_u &= \frac{s_1^2 t_{1-\frac{\alpha}{2}, \text{df}_u}^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} - \bar{y}_1^2 \end{aligned}$$

where  $s_1$  and  $s_2$  are the within-class-level standard deviations defined in the section “[Normal Difference \(DIST=NORMAL TEST=DIFF\)](#)” on page 9926 for the two-independent-sample design. If  $a_u \geq 0$  (which occurs when  $\bar{y}_2$  is too close to zero), then the unpooled Satterthwaite-based two-sided  $100(1-\alpha)\%$  confidence interval for  $\mu_r$  does not exist. If  $a_u < 0$ , then the interval is

$$\left( -\frac{b_u}{a_u} + \frac{(b_u^2 - a_u c_u)^{\frac{1}{2}}}{a_u}, -\frac{b_u}{a_u} - \frac{(b_u^2 - a_u c_u)^{\frac{1}{2}}}{a_u} \right)$$

The  $t$  test assuming unequal variances is the test derived in Tamhane and Logan (2004). The hypothesis  $H_0: \mu_r = \mu_0$  is rewritten as  $H_0: \mu_1 - \mu_0 \mu_2 = 0$ , and the Satterthwaite  $t$  test in the section “[Normal Difference \(DIST=NORMAL TEST=DIFF\)](#)” on page 9926 for the two-independent-sample design is conducted on the original  $y_{1i}$  values ( $i \in \{1, \dots, n_1^*\}$ ) and transformed values of  $y_{2i}$

$$y_{2i}^* = \mu_0 y_{2i} \quad , \quad i \in \{1, \dots, n_2^*\}$$

with a null difference of 0. The degrees of freedom are computed as

$$\text{df}_u = \frac{\left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{\mu_0^2 s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^2}{\frac{s_1^4}{(n_1-1) \left( \sum_{i=1}^{n_1^*} f_{1i} w_{1i} \right)^2} + \frac{\mu_0^4 s_2^4}{(n_2-1) \left( \sum_{i=1}^{n_2^*} f_{2i} w_{2i} \right)^2}}$$



The  $t$  value for the Satterthwaite-based unpooled test is computed as

$$t_u = \frac{\bar{y}_1 - \mu_0 \bar{y}_2}{\left( \frac{s_1^2}{\sum_{i=1}^{n_1^*} f_{1i} w_{1i}} + \frac{\mu_0^2 s_2^2}{\sum_{i=1}^{n_2^*} f_{2i} w_{2i}} \right)^{\frac{1}{2}}}$$

The  $p$ -value of the test is computed as

$$p\text{-value} = \begin{cases} P\left(t_u^2 > F_{1-\alpha, 1, \text{df}_u^*}\right) & , \quad 2\text{-sided} \\ P\left(t_u < t_{\alpha, \text{df}_u^*}\right) & , \quad \text{lower 1-sided} \\ P\left(t_u > t_{1-\alpha, \text{df}_u^*}\right) & , \quad \text{upper 1-sided} \end{cases}$$

## AB/BA Crossover Design

Let “A” and “B” denote the two treatment values. Define the following notation:

$n_1^*$  = number of observations with treatment sequence AB

$n_2^*$  = number of observations with treatment sequence BA

$y_{11i}$  = response value of  $i$ th observation in sequence AB during period 1,  $i \in \{1, \dots, n_1^*\}$

$y_{12i}$  = response value of  $i$ th observation in sequence AB during period 2,  $i \in \{1, \dots, n_1^*\}$

$y_{21i}$  = response value of  $i$ th observation in sequence BA during period 1,  $i \in \{1, \dots, n_2^*\}$

$y_{22i}$  = response value of  $i$ th observation in sequence BA during period 2,  $i \in \{1, \dots, n_2^*\}$

So  $\{y_{11i}, \dots, y_{11n_1^*}\}$  and  $\{y_{22i}, \dots, y_{22n_2^*}\}$  are all observed at treatment level A, and  $\{y_{12i}, \dots, y_{12n_1^*}\}$  and  $\{y_{21i}, \dots, y_{21n_2^*}\}$  are all observed at treatment level B.

Define the *period difference* for an observation as the difference between period 1 and period 2 response values:

$$\text{pd}_{kji} = y_{k1i} - y_{k2i}$$

for  $k \in \{1, 2\}$  and  $i \in \{1, \dots, n_k^*\}$ . Similarly, the *period ratio* is the ratio between period 1 and period 2 response values:

$$\text{pr}_{kji} = y_{k1i} / y_{k2i}$$

The *crossover difference* for an observation is the difference between treatment A and treatment B response values:

$$\text{cd}_{kji} = \begin{cases} y_{k1i} - y_{k2i} & , \quad k = 1 \\ y_{k2i} - y_{k1i} & , \quad k = 2 \end{cases}$$

Similarly, the *crossover ratio* is the ratio between treatment A and treatment B response values:

$$\text{cr}_{kji} = \begin{cases} y_{k1i} / y_{k2i} & , \quad k = 1 \\ y_{k2i} / y_{k1i} & , \quad k = 2 \end{cases}$$

In the absence of the **IGNOREPERIOD** option in the **PROC TTEST** statement, the data are split into two groups according to treatment sequence and analyzed as a two-independent-sample design. If

**DIST=NORMAL**, then the analysis of the treatment effect is based on the half period differences  $\{pd_{kji}/2\}$ , and the analysis for the period effect is based on the half crossover differences  $\{cd_{kji}/2\}$ . The computations for the normal difference analysis are the same as in the section “**Normal Difference (DIST=NORMAL TEST=DIFF)**” on page 9926 for the two-independent-sample design. The normal ratio analysis without the **IGNOREPERIOD** option is not supported for the AB/BA crossover design. If **DIST=LOGNORMAL**, then the analysis of the treatment effect is based on the square root of the period ratios  $\{\sqrt{pr_{kji}}\}$ , and the analysis for the period effect is based on the square root of the crossover ratios  $\{\sqrt{cr_{kji}}\}$ . The computations are the same as in the section “**Lognormal Ratio (DIST=LOGNORMAL TEST=RATIO)**” on page 9928 for the two-independent-sample design.

If the **IGNOREPERIOD** option is specified, then the treatment effect is analyzed as a paired analysis on the (treatment A, treatment B) response value pairs, regardless of treatment sequence. So the set of pairs is taken to be the concatenation of  $\{(y_{111}, y_{121}), \dots, (y_{11n_1^*}, y_{12n_1^*})\}$  and  $\{(y_{221}, y_{211}), \dots, (y_{22n_2^*}, y_{21n_2^*})\}$ . The computations are the same as in the section “**Paired Design**” on page 9925.

See Senn (2002, Chapter 3) for a more detailed discussion of the AB/BA crossover design.

## TOST Equivalence Test

The hypotheses for an equivalence test are

$$\begin{aligned} H_0: \mu < \theta_L \quad \text{or} \quad \mu > \theta_U \\ H_1: \theta_L \leq \mu \leq \theta_U \end{aligned}$$

where  $\theta_L$  and  $\theta_U$  are the lower and upper bounds specified in the **TOST** option in the **PROC TTEST** statement, and  $\mu$  is the analysis criterion (mean, mean ratio, or mean difference, depending on the analysis). Following the two one-sided tests (TOST) procedure of Schuirmann (1987), the equivalence test is conducted by performing two separate tests:

$$\begin{aligned} H_{a0}: \mu < \theta_L \\ H_{a1}: \mu \geq \theta_L \end{aligned}$$

and

$$\begin{aligned} H_{b0}: \mu > \theta_U \\ H_{b1}: \mu \leq \theta_U \end{aligned}$$

The overall  $p$ -value is the larger of the two  $p$ -values of those tests.

Rejection of  $H_0$  in favor of  $H_1$  at significance level  $\alpha$  occurs if and only if the  $100(1 - 2\alpha)\%$  confidence interval for  $\mu$  is contained completely within  $(\theta_L, \theta_U)$ . So, the  $100(1 - 2\alpha)\%$  confidence interval for  $\mu$  is displayed in addition to the usual  $100(1 - \alpha)\%$  interval.

For further discussion of equivalence testing for the designs supported in the TTEST procedure, see Phillips (1990); Diletti, Hauschke, and Steinijans (1991); Hauschke et al. (1999).

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## Displayed Output

For an AB/BA crossover design, the CrossoverVarInfo table shows the variables specified for the response and treatment values in each period of the design.

The summary statistics in the Statistics table and confidence limits in the ConfLimits table are displayed for certain variables and/or transformations or subgroups of the variables in the analysis, depending on the design. For a one-sample design, summary statistics are displayed for all variables in the analysis. For a paired design, statistics are displayed for the difference if you specify the **TEST=DIFF** option in the **PROC TTEST** statement, or for the ratio if you specify **TEST=RATIO**. For a two-independent-sample design, the statistics for each of the two groups and for the difference (if **TEST=DIFF**) or ratio (if **TEST=RATIO**) are displayed. For an AB/BA crossover design, statistics are displayed for each of the four cells in the design (all four combinations of the two periods and two treatments). If the **IGNOREPERIOD** option is absent, then if **TEST=DIFF** is specified, statistics are displayed for the treatment difference within each sequence and overall, and also for the period difference. If **TEST=RATIO**, statistics are displayed for the treatment ratio within each sequence and overall, and also for the period ratio. If the **IGNOREPERIOD** option is specified in the **VAR** statement, then statistics are displayed for the overall treatment difference if **TEST=DIFF** or for the overall treatment ratio if **TEST=RATIO**.

The Statistics table displays the following summary statistics:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- the name of the classification variable (if two-independent-sample design) or treatment and period (if AB/BA crossover design)
- N, the number of nonmissing values
- the (arithmetic) Mean, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement
- the Geometric Mean, displayed if the **DIST=LOGNORMAL** option is specified in the **PROC TTEST** statement
- Std Dev, the standard deviation, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement
- the Coefficient of Variation, displayed if the **DIST=LOGNORMAL** option is specified in the **PROC TTEST** statement
- Std Err, the standard error of the mean, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement
- the Minimum value
- the Maximum value

The ConfLimits table displays the following:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- the name of the classification variable (if two-independent-sample design) or treatment and period (if AB/BA crossover design)
- the (arithmetic) Mean, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement

- the Geometric Mean, displayed if the **DIST=LOGNORMAL** option is specified in the **PROC TTEST** statement
- $100(1 - \alpha)\%$  CL Mean, the lower and upper confidence limits for the mean. Separate pooled and Satterthwaite confidence limits are shown for the difference or ratio transformations in two-independent-sample designs and AB/BA crossover designs without the **IGNOREPERIOD** option.
- Std Dev, the standard deviation, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement
- the Coefficient of Variation, displayed if the **DIST=LOGNORMAL** option is specified in the **PROC TTEST** statement
- $100(1 - \alpha)\%$  CL Std Dev, the equal-tailed confidence limits for the standard deviation, displayed if the **DIST=NORMAL** and **CI=EQUAL** options are specified in the **PROC TTEST** statement
- $100(1 - \alpha)\%$  UMPU CL Std Dev, the UMPU confidence limits for the standard deviation, displayed if the **DIST=NORMAL** and **CI=UMPU** options are specified in the **PROC TTEST** statement
- $100(1 - \alpha)\%$  CL CV, the equal-tailed confidence limits for the coefficient of variation, displayed if the **DIST=LOGNORMAL** and **CI=EQUAL** options are specified in the **PROC TTEST** statement
- $100(1 - \alpha)\%$  UMPU CL CV, the UMPU confidence limits for the coefficient of variation, displayed if the **DIST=LOGNORMAL** and **CI=UMPU** options are specified in the **PROC TTEST** statement

The confidence limits in the **EquivLimits** table and test results in the **TTests** and **EquivTests** tables are displayed only for the test criteria—that is, the variables or transformations being tested. For a one-sample design, results are displayed for all variables in the analysis. For a paired design, results are displayed for the difference if you specify the **TEST=DIFF** option in the **PROC TTEST** statement, or for the ratio if you specify **TEST=RATIO**. For a two-independent-sample design, the results for the difference (if **TEST=DIFF**) or ratio (if **TEST=RATIO**) are displayed. For an AB/BA crossover design, results are displayed for the treatment difference (if **TEST=DIFF**) or ratio (if **TEST=RATIO**). If the **IGNOREPERIOD** option is absent, then results are also displayed for the period difference (if **TEST=DIFF**) or ratio (if **TEST=RATIO**).

The **EquivLimits** table, produced only if the **TOST** option is specified in the **PROC TTEST** statement, displays the following:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- the (arithmetic) Mean, displayed if the **DIST=NORMAL** option is specified in the **PROC TTEST** statement
- the Geometric Mean, displayed if the **DIST=LOGNORMAL** option is specified in the **PROC TTEST** statement
- Lower Bound, the lower equivalence bound for the mean specified in the **TOST** option in the **PROC TTEST** statement
- $100(1 - 2\alpha)\%$  CL Mean, the lower and upper confidence limits for the mean relevant to the equivalence test. Separate pooled and Satterthwaite confidence limits are shown for two-independent-sample designs and AB/BA crossover designs without the **IGNOREPERIOD** option.

- Upper Bound, the upper equivalence bound for the mean specified in the **TOST** option in the **PROC TTEST** statement
- Assessment, the result of the equivalence test at the significance level specified by the **ALPHA=** option in the **PROC TTEST** statement, either “Equivalent” or “Not equivalent”

The TTests table is produced only if the **TOST** option is *not* specified in the **PROC TTEST** statement. Separate results for pooled and Satterthwaite tests (and also the Cochran and Cox test, if the **COCHRAN** option is specified in the **PROC TTEST** statement) are displayed for two-independent-sample designs and AB/BA crossover designs without the **IGNOREPERIOD** option. The table includes the following results:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- t Value, the  $t$  statistic for comparing the mean to the null value as specified by the **H0=** option in the **PROC TTEST** statement
- DF, the degrees of freedom
- the  $p$ -value, the probability of obtaining a  $t$  statistic at least as extreme as the observed  $t$  value under the null hypothesis

The EquivTests table is produced only if the **TOST** option is specified in the **PROC TTEST** statement. Separate results for pooled and Satterthwaite tests are displayed for two-independent-sample designs and AB/BA crossover designs without the **IGNOREPERIOD** option. Each test consists of two separate one-sided tests. The overall  $p$ -value is the larger  $p$ -value from these two tests. The table includes the following results:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- Null, the lower equivalence bound for the Upper test or the upper equivalence bound for the Lower test, as specified by the **TOST** option in the **PROC TTEST** statement
- t Value, the  $t$  statistic for comparing the mean to the Null value
- DF, the degrees of freedom
- the  $p$ -value, the probability of obtaining a  $t$  statistic at least as extreme as the observed  $t$  value under the null hypothesis

The Equality table gives the results of the test of equality of variances. It is displayed for two-independent-sample designs and AB/BA crossover designs without the **IGNOREPERIOD** option. The table includes the following results:

- the name of the variable(s), displayed if the **NOBYVAR** option is used in the **PROC TTEST** statement
- Num DF and Den DF, the numerator and denominator degrees of freedom
- F Value, the  $F'$  (folded) statistic
- Pr > F, the probability of a greater  $F'$  value. This is the two-tailed  $p$ -value.

## ODS Table Names

PROC TTEST assigns a name to each table it creates. You can use these names to reference the table when using the Output Delivery System (ODS) to select tables and create output data sets. These names are listed in Table 121.5. For more information about ODS, see Chapter 20, “Using the Output Delivery System.”

**Table 121.5** ODS Tables Produced by PROC TTEST

ODS Table Name	Description	Syntax
ConfLimits	100(1 – $\alpha$ )% confidence limits for means, standard deviations, and/or coefficients of variation	By default
Equality	Tests for equality of variance	CLASS statement or VAR / CROSSOVER=
EquivLimits	100(1 – 2 $\alpha$ )% confidence limits for means	PROC TTEST TOST
EquivTests	Equivalence <i>t</i> tests	PROC TTEST TOST
Statistics	Univariate summary statistics	By default
TTests	<i>t</i> tests	By default

## ODS Graphics

Statistical procedures use ODS Graphics to create graphs as part of their output. ODS Graphics is described in detail in Chapter 21, “Statistical Graphics Using ODS.”

Before you create graphs, ODS Graphics must be enabled (for example, by specifying the ODS GRAPHICS ON statement). For more information about enabling and disabling ODS Graphics, see the section “Enabling and Disabling ODS Graphics” on page 607 in Chapter 21, “Statistical Graphics Using ODS.”

The overall appearance of graphs is controlled by ODS styles. Styles and other aspects of using ODS Graphics are discussed in the section “A Primer on ODS Statistical Graphics” on page 606 in Chapter 21, “Statistical Graphics Using ODS.”

## ODS Graph Names

You can reference every graph produced through ODS Graphics with a name. The names of the graphs that PROC TTEST generates are listed in Table 121.6, along with the required statements and options.

**Table 121.6** Graphs Produced by PROC TTEST

ODS Graph Name	Plot Description	Option
AgreementOfPeriods	Plot of period 2 against period 1 response values for an AB/BA crossover design	VAR / CROSSOVER= PLOTS=AGREEMENT(TYPE=PERIOD)

**Table 121.6** *continued*

ODS Graph Name	Plot Description	Option
AgreementOfTreatments	Plot of second treatment against first treatment response values for an AB/BA crossover design	VAR / CROSSOVER= PLOTS=AGREEMENT
AgreementPlot	Plot of second response against first response for a paired design	PAIRED statement PLOTS=AGREEMENT
BoxPlot	Box plots, also with confidence band for one-sample or paired design	PLOTS=BOX PLOTS=SUMMARY(UNPACK)
Histogram	Histograms with overlaid kernel densities, and also normal densities if DIST=NORMAL	PLOTS=HISTOGRAM PLOTS=SUMMARY(UNPACK)
Interval	Confidence intervals for means	PLOTS=INTERVAL
ProfilesOverPrd	Plot of response profiles over periods 1 and 2 for an AB/BA crossover design	VAR / CROSSOVER= PLOTS=PROFILES(TYPE=PERIOD)
ProfilesOverTrt	Plot of response profiles over first and second treatments for an AB/BA crossover design	VAR / CROSSOVER= PLOTS=PROFILES
ProfilesPlot	Plot of response profiles over first and second response values for a paired design	PAIRED statement PLOTS=PROFILES
QQPlot	Normal quantile-quantile plots	PLOTS=QQ
SummaryPanel	Histograms with overlaid kernel densities (and also normal densities if DIST=NORMAL) and box plots (and also with confidence band for one-sample or paired design)	PLOTS=SUMMARY

## Interpreting Graphs

### **Agreement Plots for Paired Designs**

For paired designs, the second response of each pair is plotted against the first response, with the mean shown as a large bold symbol. If the **WEIGHT** statement is used, then the mean is the weighted mean. A diagonal line with slope=1 and y-intercept=0 is overlaid. The location of the points with respect to the diagonal line reveals the strength and direction of the difference or ratio. The tighter the clustering along the same direction as the line, the stronger the positive correlation of the two measurements for each subject. Clustering along a direction perpendicular to the line indicates negative correlation.



### Period Agreement Plots for Crossover Designs

The response in the second period is plotted against the response in the first period, with plot symbols distinguishing the two treatment sequences and the two sequence means shown larger in bold. If the **WEIGHT** statement is used, then the means are weighted means. A diagonal line with slope=1 and y-intercept=0 is overlaid.

In the absence of a strong period effect, the points from each sequence will appear as mirror images about the diagonal line, farther apart with stronger treatment effects. Deviations from symmetry about the diagonal line indicate a period effect. The spread of points within each treatment sequence is an indicator of between-subject variability. The tighter the clustering along the same direction as the line (within each treatment sequence), the stronger the positive correlation of the two measurements for each subject. Clustering along a direction perpendicular to the line indicates negative correlation.

The period agreement plot is usually less informative than the treatment agreement plot. The exception is when the period effect is stronger than the treatment effect.

### Treatment Agreement Plots for Crossover Designs

The response associated with the second treatment is plotted against the response associated with the first treatment, with plot symbols distinguishing the two treatment sequences and the two sequence means shown larger in bold. If the **WEIGHT** statement is used, then the means are weighted means. A diagonal line with slope=1 and y-intercept=0 is overlaid.

The location of the points with respect to the diagonal line reveals the strength and direction of the treatment effect. Substantial location differences between the two sequences indicates a strong period effect. The spread of points within each treatment sequence is an indicator of between-subject variability. The tighter the clustering along the same direction as the line (within each treatment sequence), the stronger the positive correlation of the two measurements for each subject. Clustering along a direction perpendicular to the line indicates negative correlation.

### Box Plots

The box is drawn from the 25th percentile (lower quartile) to the 75th percentile (upper quartile). The vertical line inside the box shows the location of the median. If **DIST=NORMAL**, then a diamond symbol shows the location of the mean. The whiskers extend to the minimum and maximum observations, and circles beyond the whiskers identify outliers.

For one-sample and paired designs, a confidence interval for the mean is shown as a band in the background. If the analysis is an equivalence analysis (with the **TOST** option in the **PROC TTEST** statement), then the interval is a  $100(1 - 2\alpha)\%$  confidence interval shown along with the equivalence bounds. The inclusion of this interval completely within the bounds is indicative of a significant  $p$ -value. If the analysis is not an equivalence analysis, then the confidence level is  $100(1 - \alpha)\%$ . If the **SHOWH0** global plot option is used, then the null value for the test is shown. If the **WEIGHT** statement is used, then weights are incorporated in the confidence intervals.

### Histograms

The **WEIGHT** statement is ignored in the computation of the normal and kernel densities.

### Confidence Intervals

If the analysis is an equivalence analysis (with the **TOST** option in the **PROC TTEST** statement), then unless the **TYPE=PERGROUP** option is used, the interval is a  $100(1 - 2\alpha)\%$  mean confidence interval shown along



with the equivalence bounds. The inclusion of this interval completely within the bounds is indicative of a significant  $p$ -value.

If the analysis is not an equivalence analysis, or if the `TYPE=PERGROUP` option is used, then the confidence level is  $100(1 - \alpha)\%$ . If the `SHOWH0` global plot option is used, then the null value for the test is shown.

If the `SIDES=L` or `SIDES=U` option is used in the `PROC TTEST` statement, then the unbounded side of the one-sided interval is represented with an arrowhead. Note that the actual location of the arrowhead is irrelevant.

If the `WEIGHT` statement is used, then weights are incorporated in the confidence intervals.

### ***Profiles for Paired Designs***

For paired designs, a line is drawn for each observation from left to right connecting the first response to the second response. The mean first response and mean second response are connected with a bold line. If the `WEIGHT` statement is used, then the means are weighted means. The more extreme the slope, the stronger the effect. A wide spread of profiles indicates high between-subject variability. Consistent positive slopes indicate strong positive correlation. Widely varying slopes indicate lack of correlation, while consistent negative slopes indicate strong negative correlation.

### ***Profiles over Period for Crossover Designs***

For each observation, the response for the first period is connected to the response for second period, regardless of the treatment applied in each period. The means for each treatment sequence are shown in bold. If the `WEIGHT` statement is used, then the means are weighted means.

In the absence of a strong period effect, the profiles for each sequence will appear as mirror images about an imaginary horizontal line in the center. Deviations from symmetry about this imaginary horizontal line indicate a period effect. A wide spread of profiles within sequence indicates high between-subject variability.

The `TYPE=PERIOD` plot is usually less informative than the `TYPE=TREATMENT` plot. The exception is when the period effect is stronger than the treatment effect.

### ***Profiles over Treatment for Crossover Designs***

For each observation, the response for the first treatment is connected to the response for the second treatment, regardless of the periods in which they occur. The means for each treatment sequence are shown in bold. If the `WEIGHT` statement is used, then the means are weighted means.

In general, the more extreme the slope, the stronger the treatment effect. Slope differences between the two treatment sequences measure the period effect. A wide spread of profiles within sequence indicates high between-subject variability.

### ***Q-Q Plots***

Q-Q plots are useful for diagnosing violations of the normality and homoscedasticity assumptions. If the data in a Q-Q plot come from a normal distribution, the points will cluster tightly around the reference line. You can use the `UNIVARIATE` procedure with the `NORMAL` option to numerically check the normality assumption.

## Examples: TTEST Procedure

### Example 121.1: Using Summary Statistics to Compare Group Means

This example, taken from Huntsberger and Billingsley (1989), compares two grazing methods using 32 steers. Half of the steers are allowed to graze continuously while the other half are subjected to controlled grazing time. The researchers want to know if these two grazing methods affect weight gain differently. The data are read by the following DATA step:

```
data graze;
  length GrazeType $ 10;
  input GrazeType $ WtGain @@;
  datalines;
controlled 45    controlled 62
controlled 96    controlled 128
controlled 120   controlled 99
controlled 28    controlled 50
controlled 109   controlled 115
controlled 39    controlled 96
controlled 87    controlled 100
controlled 76    controlled 80
continuous 94    continuous 12
continuous 26    continuous 89
continuous 88    continuous 96
continuous 85    continuous 130
continuous 75    continuous 54
continuous 112   continuous 69
continuous 104   continuous 95
continuous 53    continuous 21
;
```

The variable `GrazeType` denotes the grazing method: “controlled” is controlled grazing and “continuous” is continuous grazing. The dollar sign (\$) following `GrazeType` makes it a character variable, and the trailing at signs (@@) tell the procedure that there is more than one observation per line.

If you have summary data—that is, just means and standard deviations, as computed by PROC MEANS—then you can still use PROC TTEST to perform a simple *t* test analysis. This example demonstrates this mode of input for PROC TTEST. Note, however, that graphics are unavailable when summary statistics are used as input.

The MEANS procedure is invoked to create a data set of summary statistics with the following statements:

```
proc sort;
  by GrazeType;
run;

proc means data=graze noprint;
  var WtGain;
  by GrazeType;
  output out=newgraze;
run;
```

The NOPRINT option eliminates all printed output from the MEANS procedure. The **VAR** statement tells PROC MEANS to compute summary statistics for the WtGain variable, and the **BY** statement requests a separate set of summary statistics for each level of GrazeType. The OUTPUT OUT= statement tells PROC MEANS to put the summary statistics into a data set called newgraze so that it can be used in subsequent procedures. This new data set is displayed in [Output 121.1.1](#) by using PROC PRINT as follows:

```
proc print data=newgraze;
run;
```

The **\_STAT\_** variable contains the names of the statistics, and the GrazeType variable indicates which group the statistic is from.

**Output 121.1.1** Output Data Set of Summary Statistics

Obs	GrazeType	_TYPE_	_FREQ_	_STAT_	WtGain
1	continuous	0	16	N	16.000
2	continuous	0	16	MIN	12.000
3	continuous	0	16	MAX	130.000
4	continuous	0	16	MEAN	75.188
5	continuous	0	16	STD	33.812
6	controlled	0	16	N	16.000
7	controlled	0	16	MIN	28.000
8	controlled	0	16	MAX	128.000
9	controlled	0	16	MEAN	83.125
10	controlled	0	16	STD	30.535

The following statements invoke PROC TTEST with the newgraze data set, as denoted by the **DATA=** option:

```
proc ttest data=newgraze;
  class GrazeType;
  var WtGain;
run;
```

The **CLASS** statement contains the variable that distinguishes between the groups being compared, in this case GrazeType. The summary statistics and confidence intervals are displayed first, as shown in [Output 121.1.2](#).

**Output 121.1.2** Summary Statistics and Confidence Limits

#### The TTEST Procedure

Variable: WtGain

GrazeType	N	Mean	Std Dev	Std Err	Minimum	Maximum
continuous	16	75.1875	33.8117	8.4529	12.0000	130.0
controlled	16	83.1250	30.5350	7.6337	28.0000	128.0
Diff (1-2)		-7.9375	32.2150	11.3897		

GrazeType	Method	Mean	95% CL Mean	Std Dev	95% CL Std Dev
continuous		75.1875	57.1705 93.2045	33.8117	24.9768 52.3300
controlled		83.1250	66.8541 99.3959	30.5350	22.5563 47.2587
Diff (1-2)	Pooled	-7.9375	-31.1984 15.3234	32.2150	25.7434 43.0609
Diff (1-2)	Satterthwaite	-7.9375	-31.2085 15.3335		

In [Output 121.1.2](#), The `GrazeType` column specifies the group for which the statistics are computed. For each class, the sample size, mean, standard deviation and standard error, and maximum and minimum values are displayed. The confidence bounds for the mean are also displayed; however, since summary statistics are used as input, the confidence bounds for the standard deviation of the groups are not calculated.

[Output 121.1.3](#) shows the results of tests for equal group means and equal variances.

**Output 121.1.3** *t* Tests

Method	Variances	DF	t Value	Pr >  t
Pooled	Equal	30	-0.70	0.4912
Satterthwaite	Unequal	29.694	-0.70	0.4913

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	15	15	1.23	0.6981

A group test statistic for the equality of means is reported for both equal and unequal variances. Both tests indicate a lack of evidence for a significant difference between grazing methods ( $t = -0.70$  and  $p = 0.4912$  for the pooled test,  $t = -0.70$  and  $p = 0.4913$  for the Satterthwaite test). The equality of variances test does not indicate a significant difference in the two variances ( $F' = 1.23$ ,  $p = 0.6981$ ). Note that this test assumes that the observations in both data sets are normally distributed; this assumption can be checked in PROC UNIVARIATE by using the NORMAL option with the raw data.

Although the ability to use summary statistics as input is useful if you lack access to the original data, some of the output that would otherwise be produced in an analysis on the original data is unavailable. There are also limitations on the designs and distributional assumptions that can be used with summary statistics as input. For more information, see the section “[Input Data Set of Statistics](#)” on page 9920.

## Example 121.2: One-Sample Comparison with the FREQ Statement

This example examines children’s reading skills. The data consist of Degree of Reading Power (DRP) test scores from 44 third-grade children and are taken from Moore (1995, p. 337). Their scores are given in the following DATA step:

```
data read;
  input score count @@;
  datalines;
40 2   47 2   52 2   26 1   19 2
25 2   35 4   39 1   26 1   48 1
14 2   22 1   42 1   34 2   33 2
18 1   15 1   29 1   41 2   44 1
51 1   43 1   27 2   46 2   28 1
49 1   31 1   28 1   54 1   45 1
;
```

The following statements invoke the TTEST procedure to test if the mean test score is equal to 30.

```
ods graphics on;

proc ttest data=read h0=30;
  var score;
  freq count;
run;

ods graphics off;
```

The count variable contains the frequency of occurrence of each test score; this is specified in the **FREQ** statement. The output, shown in [Output 121.2.1](#), contains the results.

### Output 121.2.1 TTEST Results

#### The TTEST Procedure

Variable: score

N	Mean	Std Dev	Std Err	Minimum	Maximum
44	34.8636	11.2303	1.6930	14.0000	54.0000

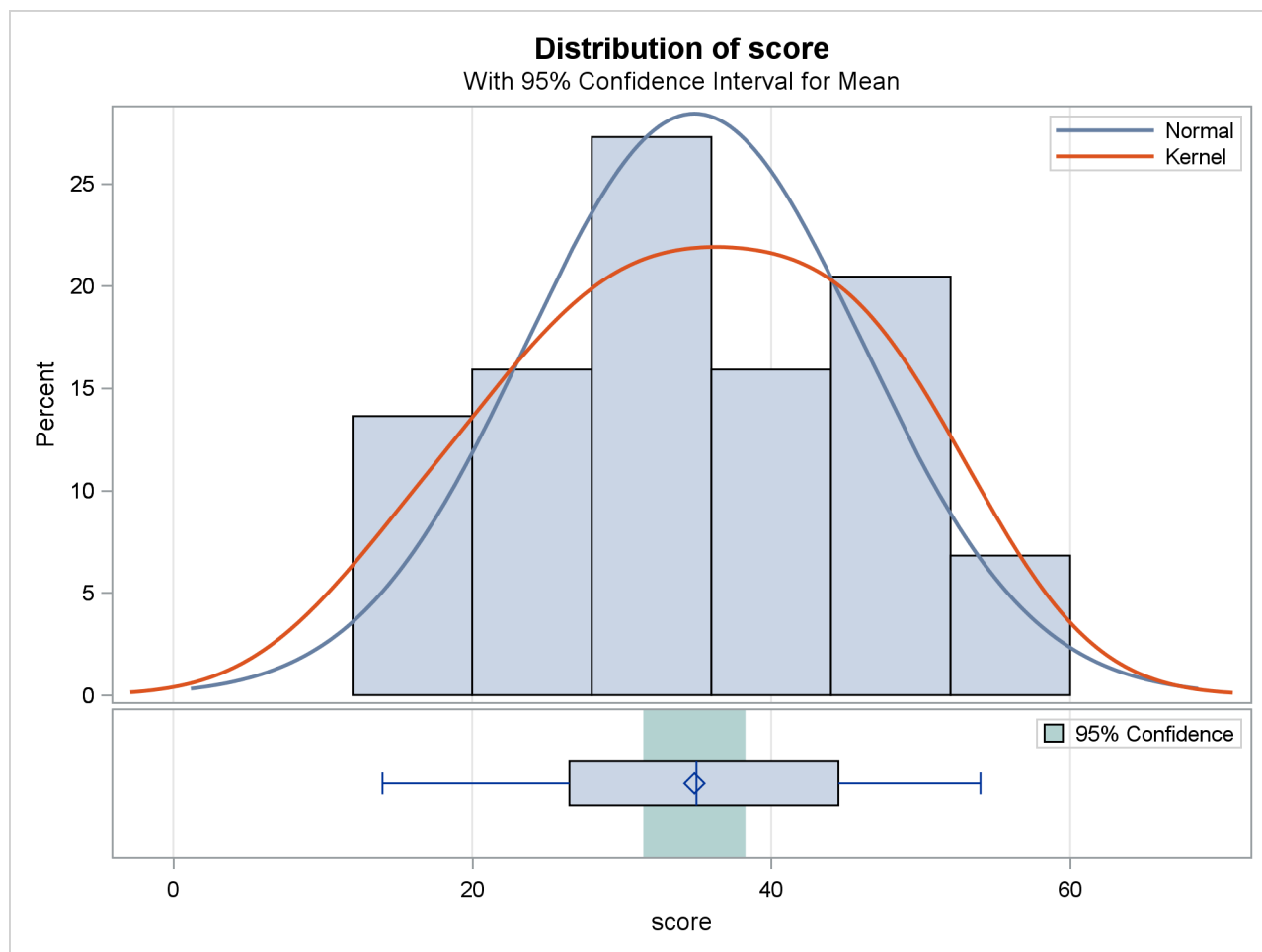
Mean	95% CL Mean	Std Dev	95% CL Std Dev
34.8636	31.4493 38.2780	11.2303	9.2788 14.2291

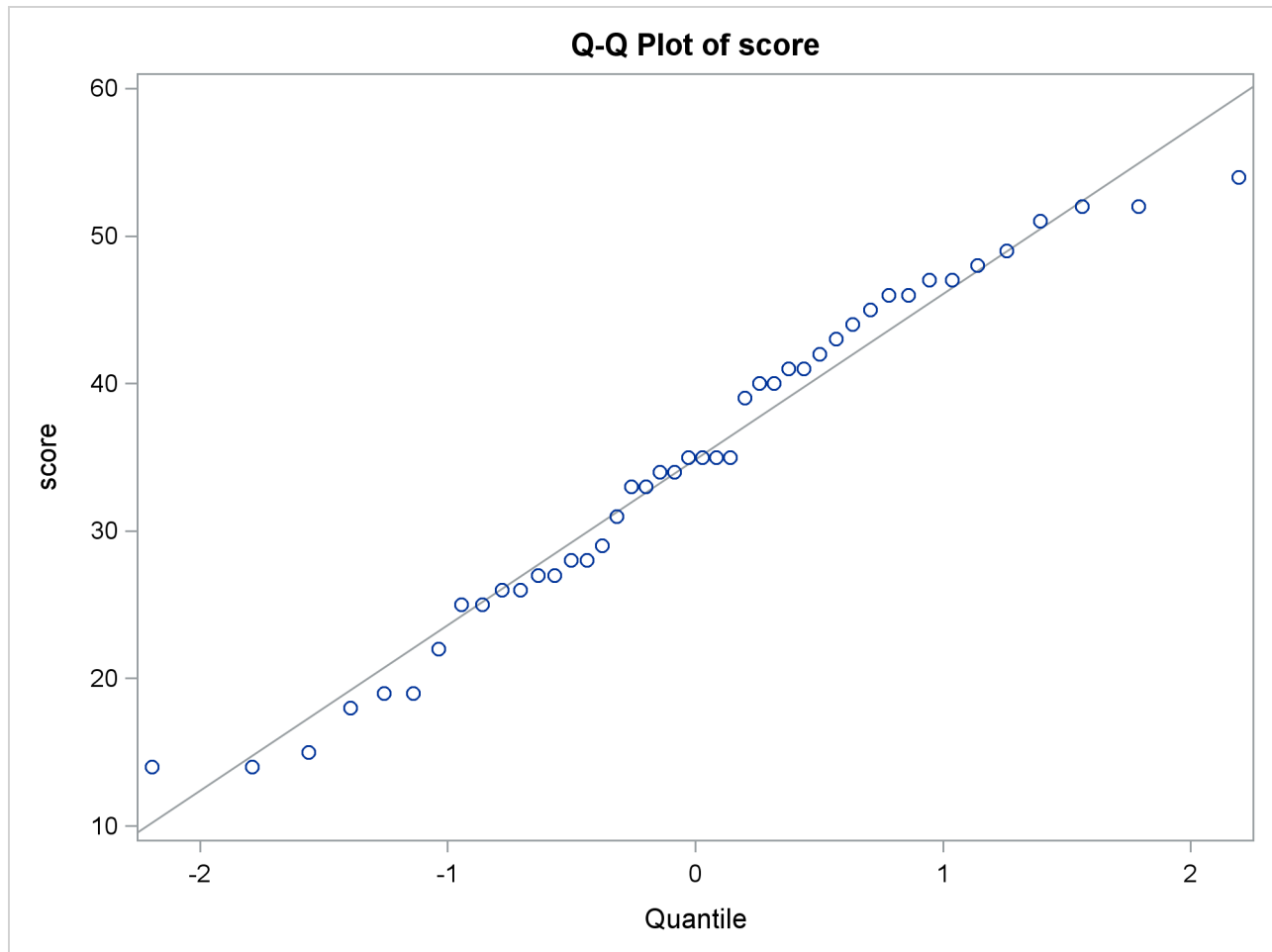
DF	t Value	Pr >  t
43	2.87	0.0063

The SAS log states that 30 observations and two variables have been read. However, the sample size given in the TTEST output is N=44. This is due to specifying the count variable in the **FREQ** statement. The test is significant ( $t = 2.87$ ,  $p = 0.0063$ ) at the 5% level, so you can conclude that the mean test score is different from 30.

The summary panel in [Output 121.2.2](#) shows a histogram with overlaid normal and kernel densities, a box plot, and the 95% confidence interval for the mean.

**Output 121.2.2** Summary Panel

The Q-Q plot in [Output 121.2.3](#) assesses the normality assumption.

**Output 121.2.3** Q-Q Plot

The tight clustering of the points around the diagonal line is consistent with the normality assumption. You could use the UNIVARIATE procedure with the NORMAL option to numerically check the normality assumption.

---

### Example 121.3: Paired Comparisons

When it is not feasible to assume that two groups of data are independent, and a natural pairing of the data exists, it is advantageous to use an analysis that takes the correlation into account. Using this correlation results in higher power to detect existing differences between the means. The differences between paired observations are assumed to be normally distributed. Some examples of this natural pairing are as follows:

- pre- and post-test scores for a student receiving tutoring
- fuel efficiency readings of two fuel types observed on the same automobile
- sunburn scores for two sunblock lotions, one applied to the individual's right arm, one to the left arm
- political attitude scores of husbands and wives

In this example, taken from the *SUGI Supplemental Library User's Guide, Version 5 Edition*, a stimulus is being examined to determine its effect on systolic blood pressure. Twelve men participate in the study. Each man's systolic blood pressure is measured both before and after the stimulus is applied. The following statements input the data:

```
data pressure;
  input SBPbefore SBPafter @@;
  datalines;
120 128   124 131   130 131   118 127
140 132   128 125   140 141   135 137
126 118   130 132   126 129   127 135
;
```

The variables SBPbefore and SBPafter denote the systolic blood pressure before and after the stimulus, respectively.

The statements to perform the test follow:

```
ods graphics on;

proc ttest;
  paired SBPbefore*SBPafter;
run;

ods graphics off;
```

The **PAIRED** statement is used to test whether the mean change in systolic blood pressure is significantly different from zero. The tabular output is displayed in [Output 121.3.1](#).

### Output 121.3.1 TTEST Results

#### The TTEST Procedure

**Difference: SBPbefore - SBPafter**

N	Mean	Std Dev	Std Err	Minimum	Maximum
12	-1.8333	5.8284	1.6825	-9.0000	8.0000

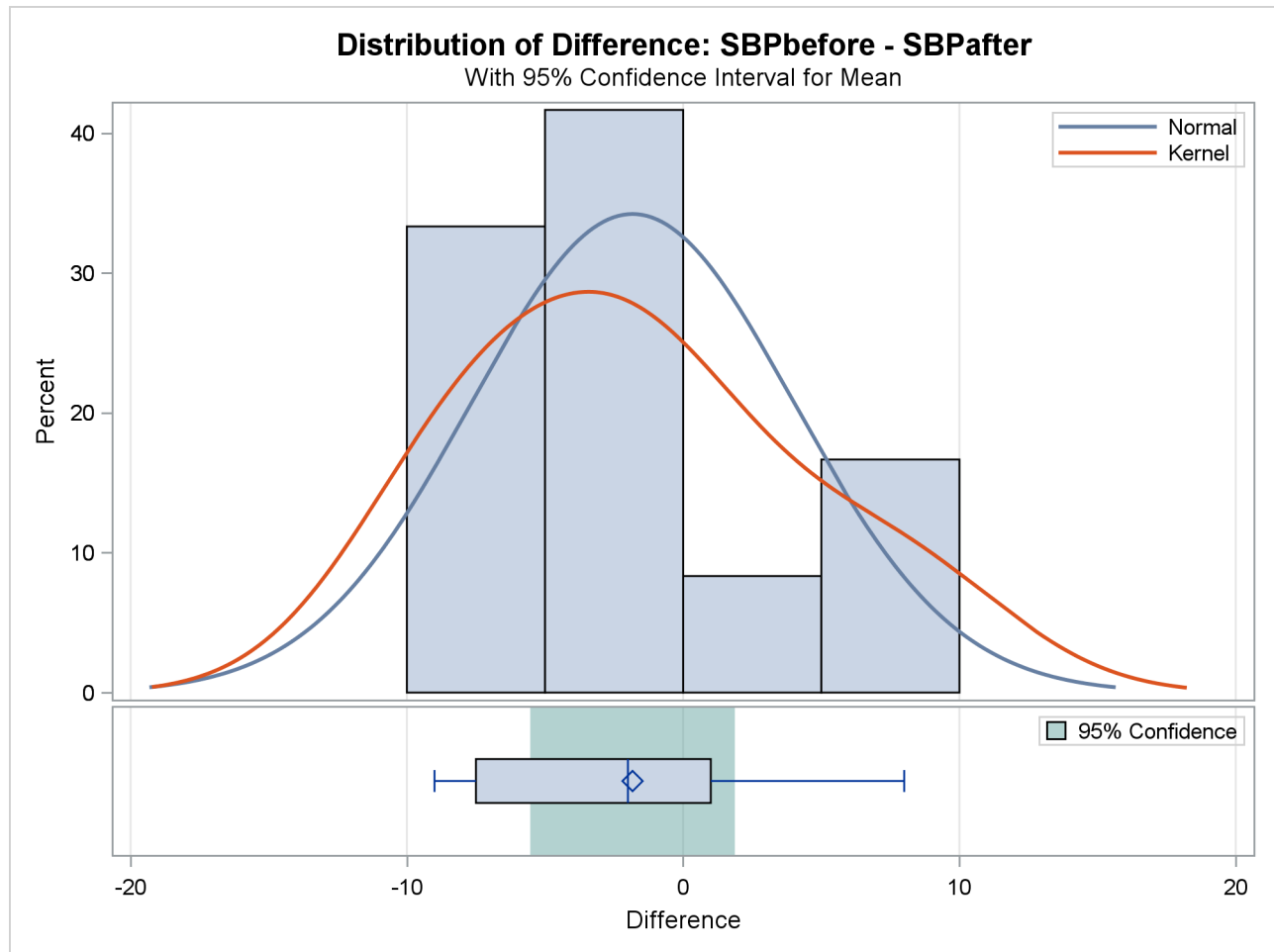
95%					
Mean	95% CL Mean	Std Dev	CL Std Dev		
-1.8333	-5.5365	1.8698	5.8284	4.1288	9.8958

DF	t Value	Pr >  t
11	-1.09	0.2992

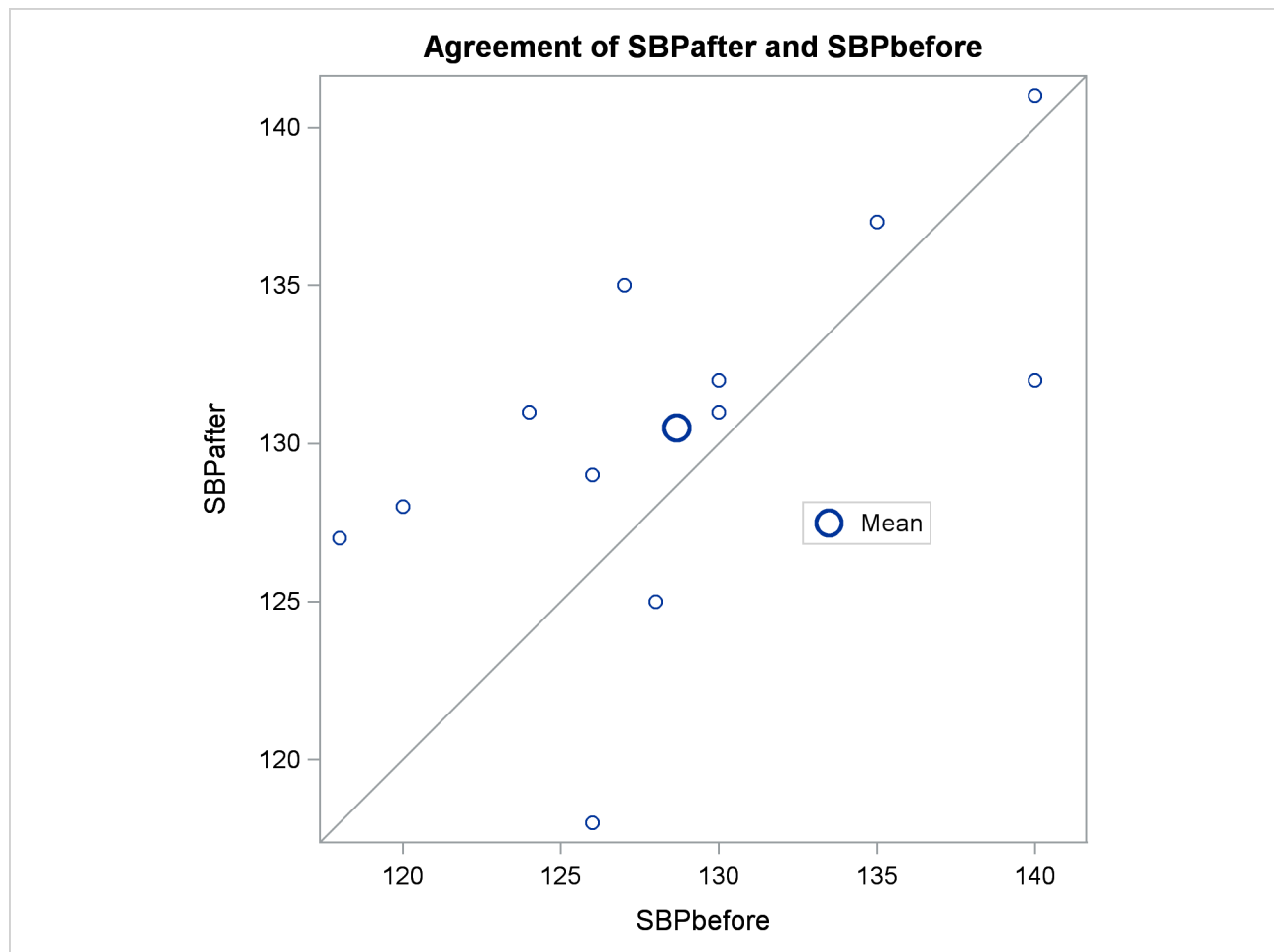
The variables SBPbefore and SBPafter are the paired variables with a sample size of 12. The summary statistics of the difference are displayed (mean, standard deviation, and standard error) along with their confidence limits. The minimum and maximum differences are also displayed. The  $t$  test is not significant ( $t = -1.09$ ,  $p = 0.2992$ ), indicating that the stimuli did not significantly affect systolic blood pressure.

The summary panel in [Output 121.3.2](#) shows a histogram, normal and kernel densities, box plot, and  $100(1 - \alpha)\% = 95\%$  confidence interval of the SBPbefore – SBPafter difference.



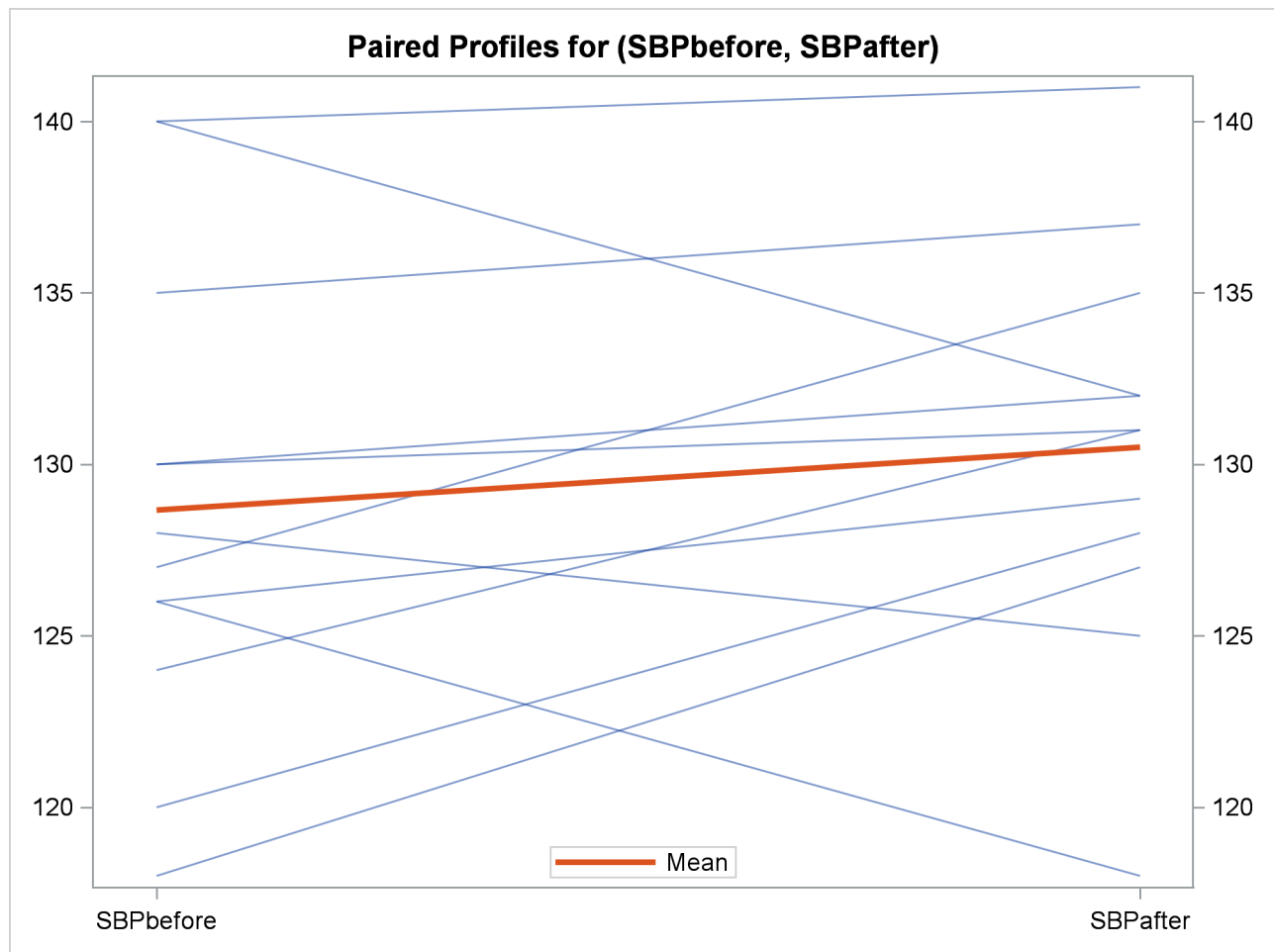
**Output 121.3.2** Summary Panel

The agreement plot in [Output 121.3.3](#) reveals that only three men have higher blood pressure before the stimulus than after.

**Output 121.3.3** Agreement of Treatments

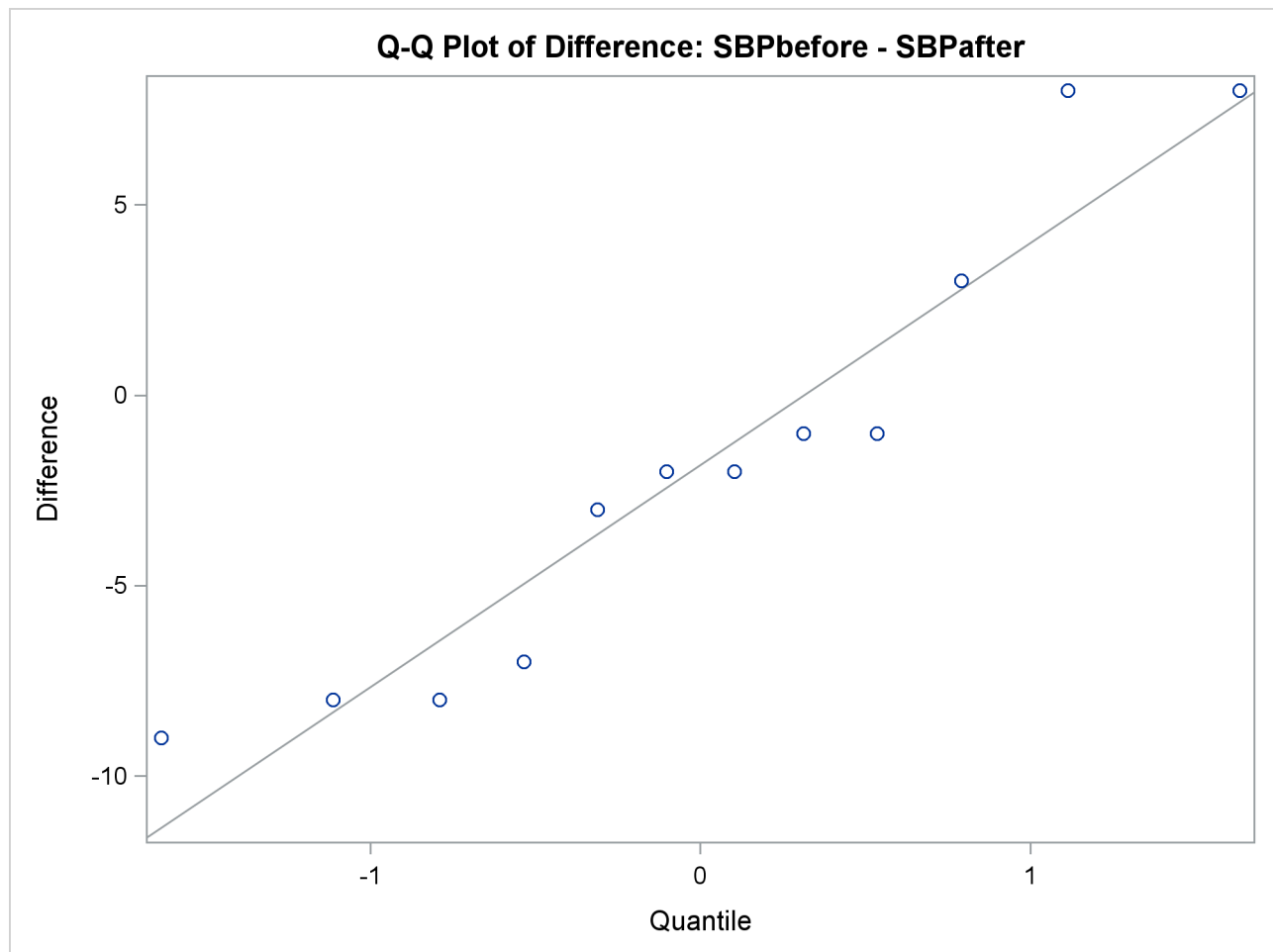
But the differences for these men are relatively large, keeping the mean difference only slightly negative.

The profiles plot in [Output 121.3.4](#) is a different view of the same information contained in [Output 121.3.3](#), plotting the blood pressure from before to after the stimulus.

**Output 121.3.4** Profiles over Treatments

The Q-Q plot in [Output 121.3.5](#) assesses the normality assumption.

Output 121.3.5 Q-Q Plot



The Q-Q plot shows no obvious deviations from normality. You can check the assumption of normality more rigorously by using PROC UNIVARIATE with the NORMAL option.

### Example 121.4: AB/BA Crossover Design

Senn (2002, Chapter 3) discusses a study comparing the effectiveness of two bronchodilators, formoterol (“for”) and salbutamol (“sal”), in the treatment of childhood asthma. A total of 13 children are recruited for an AB/BA crossover design. A random sample of 7 of the children are assigned to the treatment sequence for/sal, receiving a dose of formoterol upon an initial visit (“period 1”) and then a dose of salbutamol upon a later visit (“period 2”). The other 6 children are assigned to the sequence sal/for, receiving the treatments in the reverse order but otherwise in a similar manner. Periods 1 and 2 are sufficiently spaced so that no carryover effects are suspected. After a child inhales a dose of a bronchodilator, peak expiratory flow (PEF) is measured. Higher PEF indicates greater effectiveness. The data are assumed to be approximately normally distributed.

The data set is generated with the following statements:

```
data asthma;
  input Drug1 $ Drug2 $ PEF1 PEF2 @@;
  datalines;
for sal 310 270   for sal 310 260   for sal 370 300
for sal 410 390   for sal 250 210   for sal 380 350
for sal 330 365
sal for 370 385   sal for 310 400   sal for 380 410
sal for 290 320   sal for 260 340   sal for 90  220
;
```

You can display the data by using the following statements, which produce [Output 121.4.1](#):

```
proc print data=asthma;
run;
```

**Output 121.4.1** Asthma Study Data

Obs	Drug1	Drug2	PEF1	PEF2
1	for	sal	310	270
2	for	sal	310	260
3	for	sal	370	300
4	for	sal	410	390
5	for	sal	250	210
6	for	sal	380	350
7	for	sal	330	365
8	sal	for	370	385
9	sal	for	310	400
10	sal	for	380	410
11	sal	for	290	320
12	sal	for	260	340
13	sal	for	90	220

The variables PEF1 and PEF2 represent the responses for the first and second periods, respectively. The variables Drug1 and Drug2 represent the treatment in each period.

You can analyze this crossover design by using the **CROSSOVER=** option after a slash (/) in the **VAR** statement:

```
ods graphics on;

proc ttest data=asthma plots=interval;
  var PEF1 PEF2 / crossover= (Drug1 Drug2);
run;

ods graphics off;
```

With the default **PROC TTEST** options **TEST=DIFF** and **DIST=NORMAL** and the lack of the **IGNOREPERIOD** option in the **VAR** statement, both the treatment difference and the period difference are assessed. The **PROC TTEST** default options **H0=0**, **SIDES=2**, and **ALPHA=0.05** specify a two-sided analysis with 95% confidence limits comparing treatment and period differences to a default difference of zero. The default **CI=EQUAL** option in the **PROC TTEST** statement requests equal-tailed confidence intervals for

standard deviations. The **PLOTS=INTERVAL** option produces **TYPE=TREATMENT** confidence intervals, in addition to the default plots **AGREEMENT(TYPE=TREATMENT)**, **BOX**, **HISTOGRAM**, **PROFILES(TYPE=TREATMENT)**, and **QQ**.

Output 121.4.2 summarizes the response and treatment variables for each period.

#### Output 121.4.2 Crossover Variable Information

##### The TTEST Procedure

##### Response Variables: PEF1, PEF2

Crossover Variable Information		
Period	Response	Treatment
1	PEF1	Drug1
2	PEF2	Drug2

Output 121.4.3 displays basic summary statistics (sample size, mean, standard deviation, standard error, minimum, and maximum) for each of the four cells in the design, the treatment difference within each treatment sequence, the overall treatment difference, and the overall period difference.

#### Output 121.4.3 Statistics

Sequence	Treatment	Period	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	for	1	7	337.1	53.7631	20.3206	250.0	410.0
2	for	2	6	345.8	70.8814	28.9372	220.0	410.0
2	sal	1	6	283.3	105.4	43.0245	90.0000	380.0
1	sal	2	7	306.4	64.7247	24.4636	210.0	390.0
1	Diff (1-2)		7	30.7143	32.9682	12.4608	-35.0000	70.0000
2	Diff (1-2)		6	62.5000	44.6934	18.2460	15.0000	130.0
Both	Diff (1-2)			46.6071	19.3702	10.7766		
Both		Diff (1-2)		-15.8929	19.3702	10.7766		

The treatment difference “Diff (1-2)” corresponds to the “for” treatment minus the “sal” treatment, because “for” appears before “sal” in the output, according to the **ORDER=MIXED** default **PROC TTEST** option. Its mean estimate is 46.6071, favoring formoterol over salbutamol.

The standard deviation (Std Dev) reported for a “difference” is actually the pooled standard deviation across both treatment sequence (for/sal and sal/for), assuming equal variances. The standard error (Std Err) is the standard deviation of the mean estimate.

The top half of the table in Output 121.4.4 shows 95% two-sided confidence limits for the means for the same criteria addressed in the table in Output 121.4.3.

**Output 121.4.4** Confidence Limits

Sequence	Treatment	Period	Method	Mean	95% CL Mean	Std Dev	95% CL Std Dev	
1	for	1		337.1	287.4	386.9	53.7631	34.6446
2	for	2		345.8	271.4	420.2	70.8814	44.2447
2	sal	1		283.3	172.7	393.9	105.4	65.7841
1	sal	2		306.4	246.6	366.3	64.7247	41.7082
1	Diff (1-2)			30.7143	0.2238	61.2048	32.9682	21.2445
2	Diff (1-2)			62.5000	15.5972	109.4	44.6934	27.8980
Both	Diff (1-2)			Pooled	46.6071	22.8881	70.3262	19.3702
Both	Diff (1-2)			Satterthwaite	46.6071	21.6585	71.5558	32.8882
Both		Diff (1-2)	Pooled	-15.8929	-39.6119	7.8262	19.3702	13.7217
Both		Diff (1-2)	Satterthwaite	-15.8929	-40.8415	9.0558	32.8882	

For the mean differences, both pooled (assuming equal variances for both treatment sequences) and Satterthwaite (assuming unequal variances) intervals are shown. For example, the pooled confidence limits for the overall treatment mean difference (for – sal) assuming equal variances are 22.8881 and 70.3262.

The bottom half of [Output 121.4.4](#) shows 95% equal-tailed confidence limits for the standard deviations within each cell and for the treatment difference within each sequence. It also shows confidence limits for the pooled common standard deviation assuming equal variances. Note that the pooled standard deviation of 19.3702 and associated confidence limits 13.7217 and 32.8882 apply to both difference tests (treatment and period), since each of those tests involves the same pooled standard deviation.

[Output 121.4.5](#) shows the results of  $t$  tests of treatment and period differences.

**Output 121.4.5**  $t$  Tests

Treatment	Period	Method	Variances	DF	t Value	Pr >  t
Diff (1-2)		Pooled	Equal	11	4.32	0.0012
Diff (1-2)		Satterthwaite	Unequal	9.1017	4.22	0.0022
	Diff (1-2)	Pooled	Equal	11	-1.47	0.1683
	Diff (1-2)	Satterthwaite	Unequal	9.1017	-1.44	0.1838

Both pooled and Satterthwaite versions of the test of treatment difference are highly significant ( $p = 0.0012$  and  $p = 0.0022$ ), and both versions of the test of period difference are insignificant ( $p = 0.1683$  and  $p = 0.1838$ ).

The folded  $F$  test of equal variances in each treatment sequence is shown in [Output 121.4.6](#).

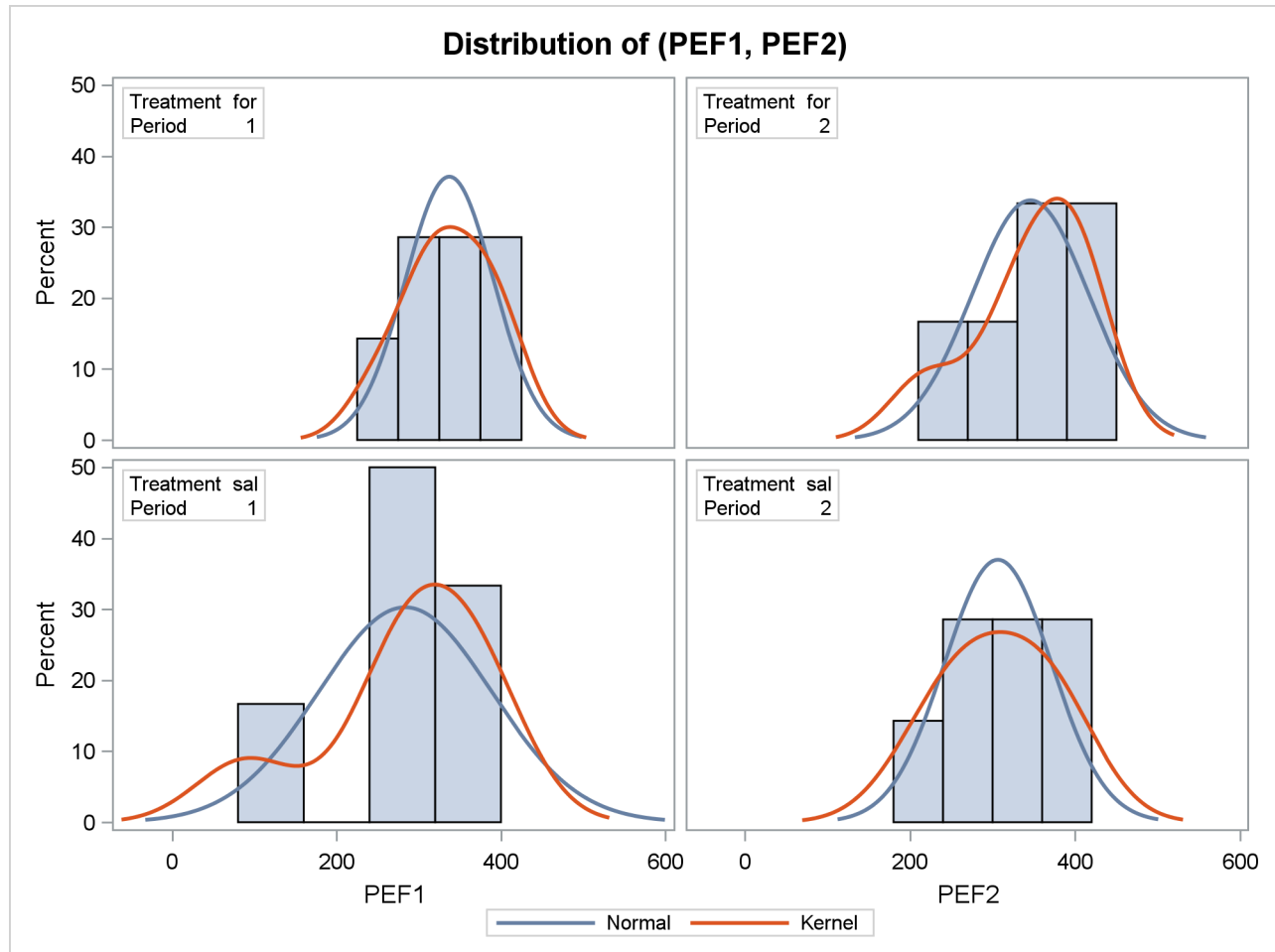
**Output 121.4.6** Equality of Variances Test

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	5	6	1.84	0.4797

The insignificant result ( $p = 0.48$ ) implies a lack of evidence for unequal variances. However, it does not demonstrate equal variances, and it is not very robust to deviations from normality.

Output 121.4.7 shows the distribution of the response variables PEF1 and PEF2 within each of the four cells (combinations of two treatments and two periods) of the AB/BA crossover design, in terms of histograms and normal and kernel density estimates.

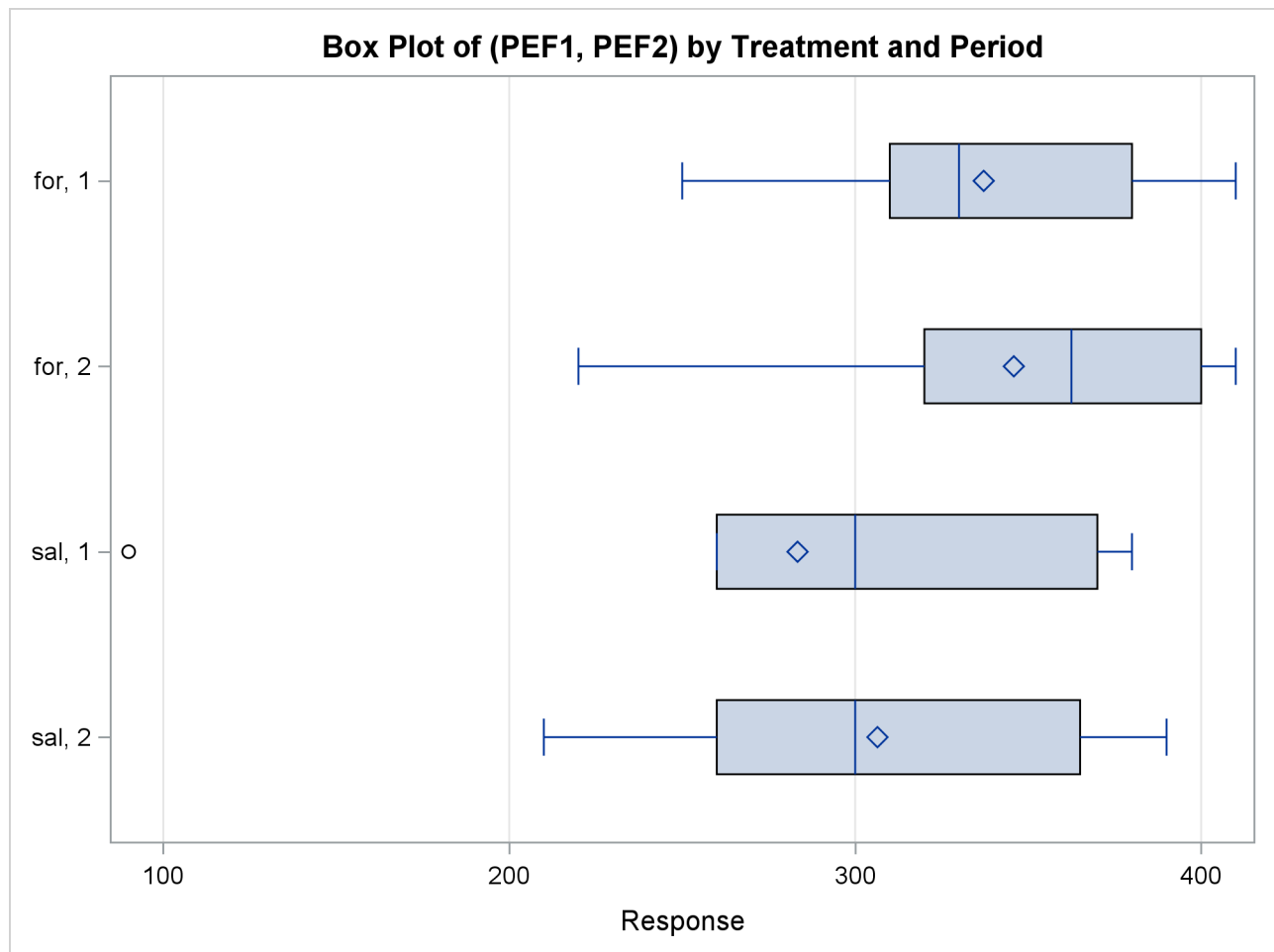
**Output 121.4.7** Comparative Histograms



The distributions for the first treatment sequence (for/sal) appear to be somewhat symmetric, and the distributions for the sal/for sequence appear to be skewed to the left.

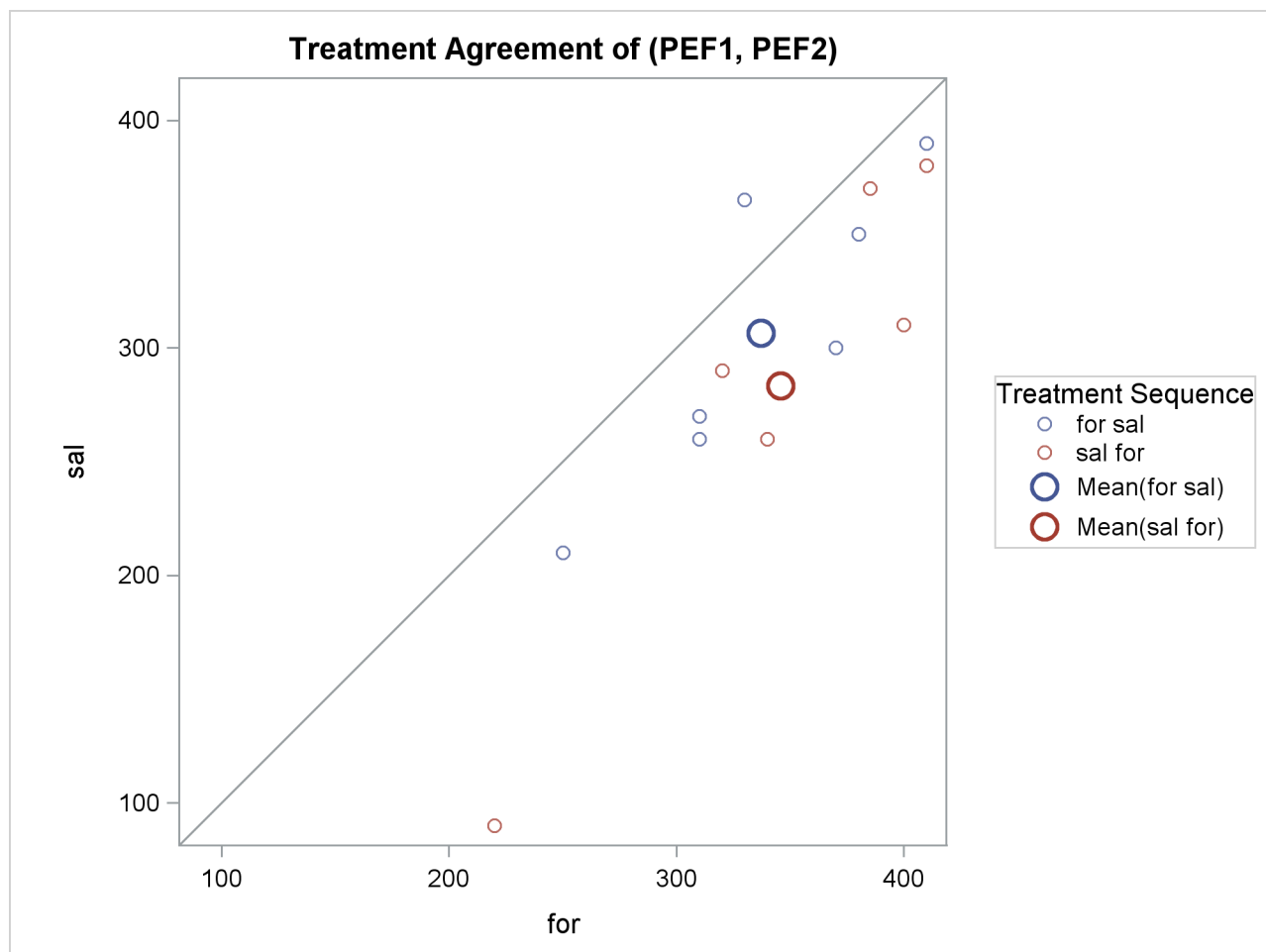
Output 121.4.8 shows a similar distributional summary but in terms of box plots.



**Output 121.4.8** Comparative Box Plots

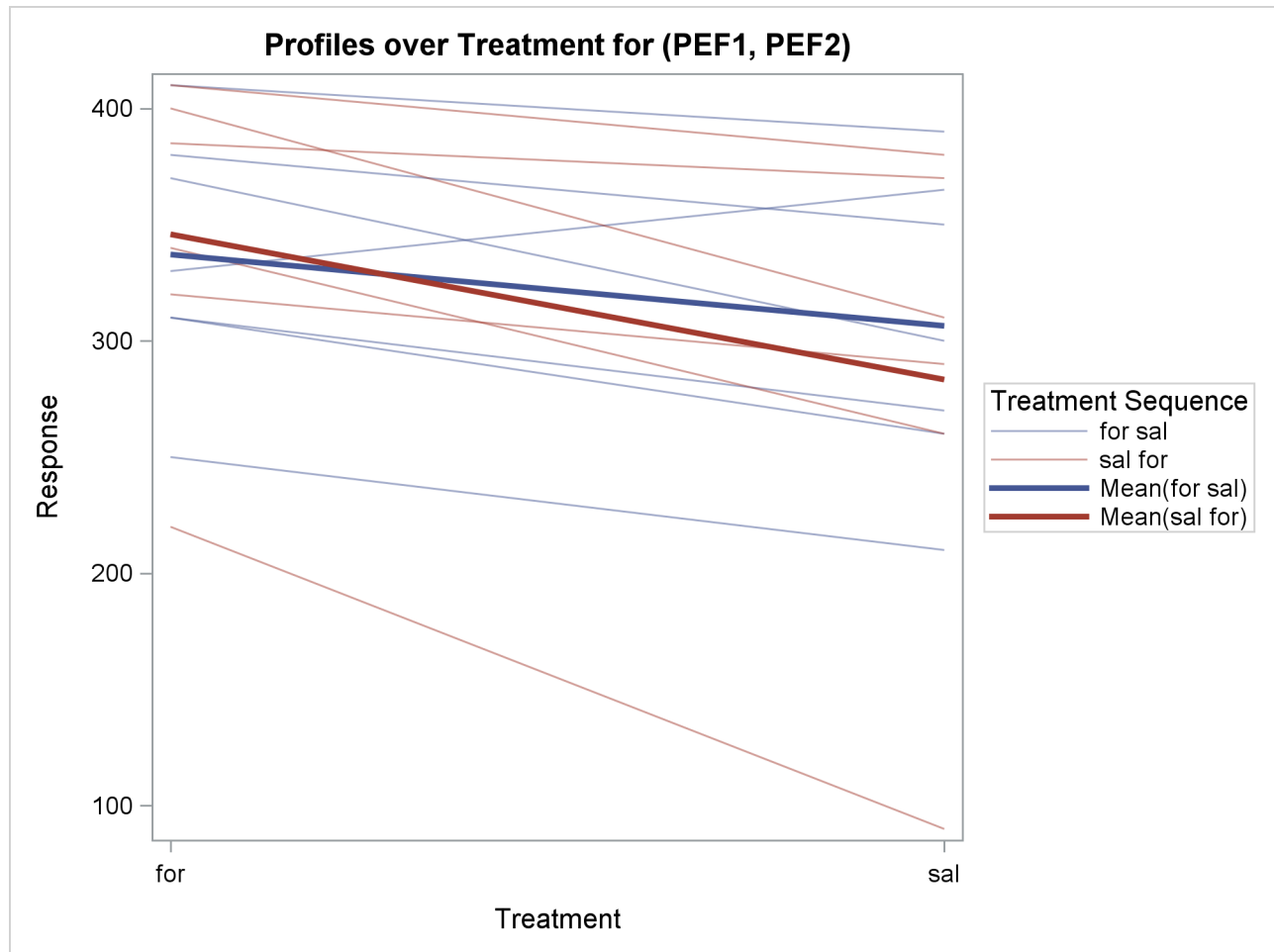
The relative locations of means and medians in each box plot corroborate the fact that the distributions for the sal/for sequence are skewed to the left. The distributions for the for/sal sequence appear to be skewed slightly to the right. The box plot for the salbutamol treatment in the first period shows an outlier (the circle on the far left side of the plot).

The treatment agreement plot in [Output 121.4.9](#) reveals that only a single observation has a higher peak expiratory flow for salbutamol.

**Output 121.4.9** Agreement of Treatments Plot

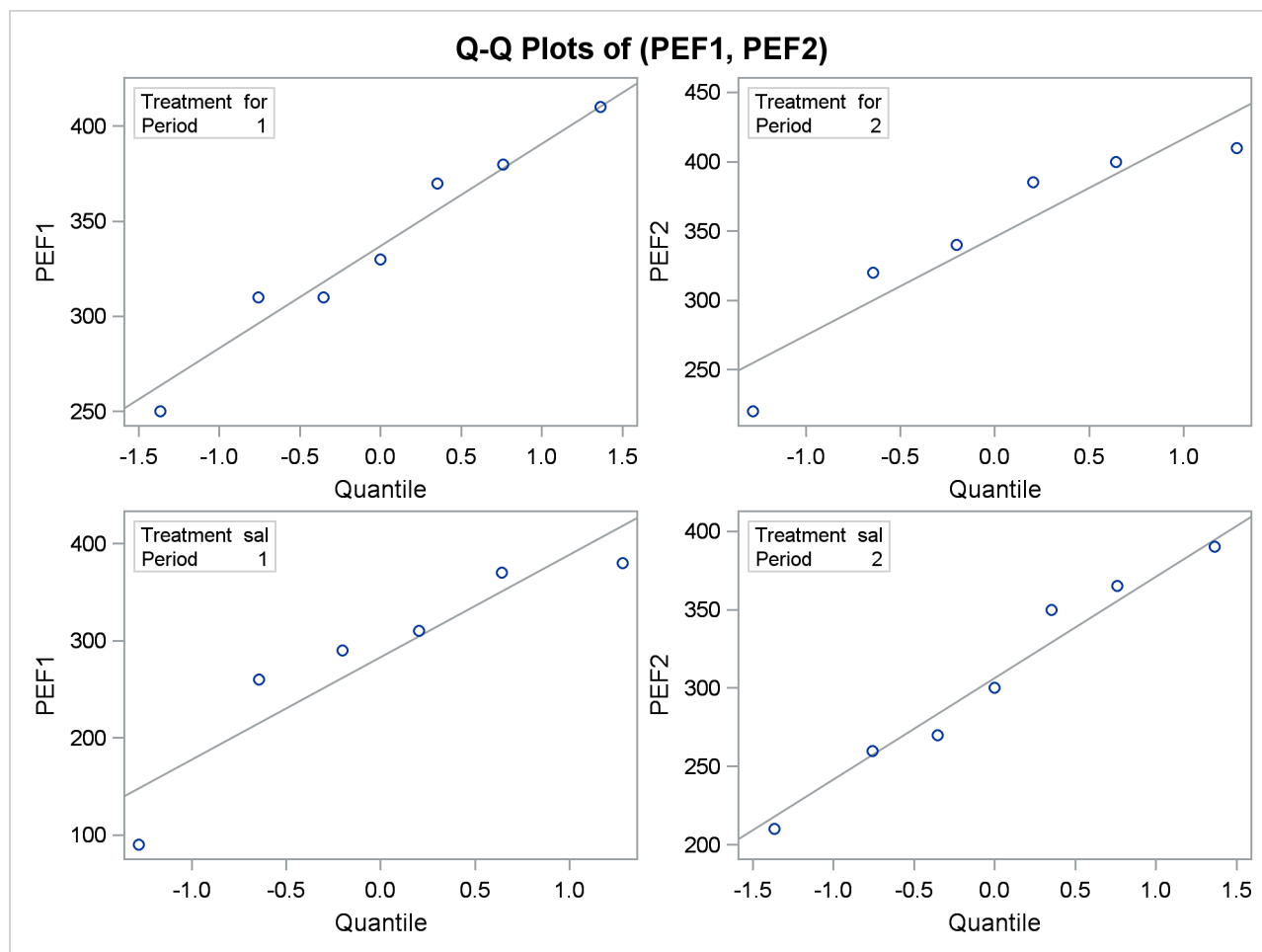
The mean for the sal/for treatment sequence is farther from the diagonal equivalence line, revealing that the treatment difference is more pronounced for the 6 observations in the sal/for sequence than for the 7 observations in the for/sal sequence. This fact is also seen numerically in [Output 121.4.3](#) and [Output 121.4.4](#), which show within-sequence treatment differences of 30.7 for for/sal and 62.5 for sal/for.

The profiles over treatment plot in [Output 121.4.10](#) is a different view of the same information contained in [Output 121.4.9](#), plotting the profiles from formoterol to salbutamol treatments. The lone observation for which the peak expiratory flow is higher for salbutamol appears as the only line with negative slope.

**Output 121.4.10** Profiles over Treatment

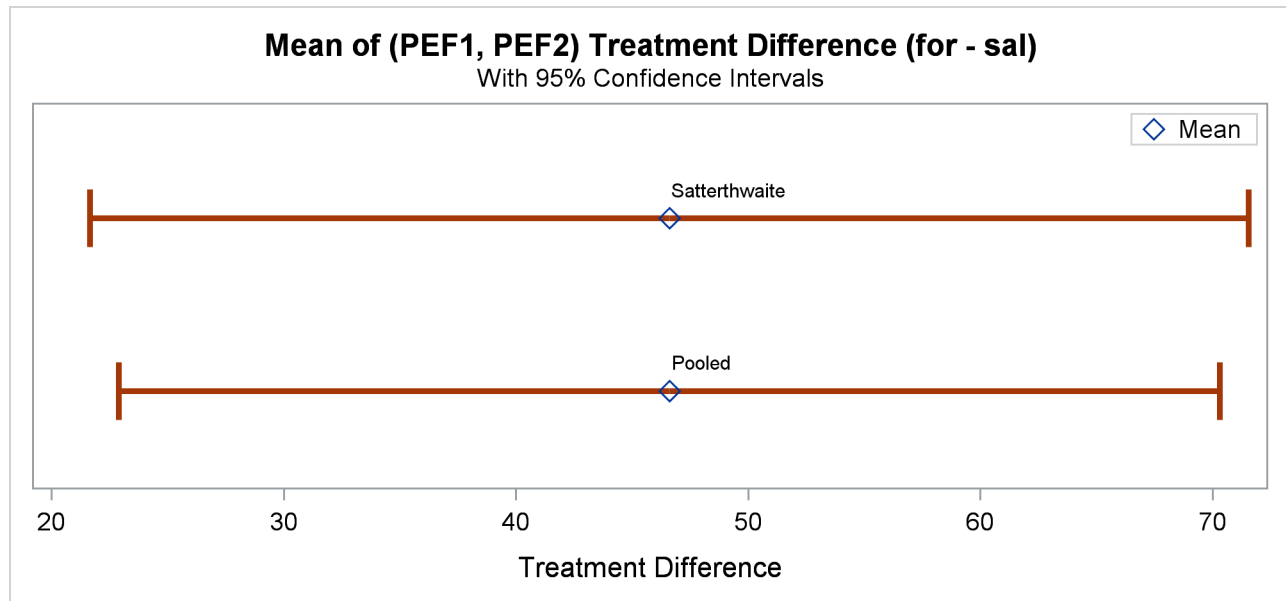
The Q-Q plots in [Output 121.4.11](#) assess normality assumption within each of the four cells of the design.

Output 121.4.11 Q-Q Plots



The two Q-Q plots for the sal/for sequence (lower left and upper right) suggest some possible normality violations in the tails, but the sample size is too small to make any strong conclusions. You could use the UNIVARIATE procedure with the NORMAL option to numerically check the normality assumptions.

Finally, [Output 121.4.12](#) shows both pooled and Satterthwaite two-sided 95% confidence intervals for the treatment difference.

**Output 121.4.12** Confidence Intervals for Treatment Difference

The pooled interval is slightly smaller than the Satterthwaite interval. (This is not always the case.)

## Example 121.5: Equivalence Testing with Lognormal Data

Wellek (2003, p. 212) discusses an average bioequivalence study comparing the AUC (area under serum-concentration curve) measurements for two different drugs, denoted “Test” and “Reference,” over a period of 20 hours. This example looks at a portion of Wellek’s data, conducting an equivalence analysis with a paired design that uses AUC values on the original scale (assumed to be lognormally distributed). Each subject in the study received the Test drug upon one visit and then the Reference drug upon a later visit, sufficiently spaced so that no carryover effects would occur.

The goal is to test whether the geometric mean AUC ratio between Test and Reference is between 0.8 and 1.25, corresponding to the traditional FDA (80%, 125%) equivalence criterion. See the section “[Arithmetic and Geometric Means](#)” on page 9921 for a discussion of the use of geometric means for lognormal data.

The following SAS statements generate the data set:

```
data auc;
  input TestAUC RefAUC @@;
  datalines;
103.4 90.11 59.92 77.71 68.17 77.71 94.54 97.51
69.48 58.21 72.17 101.3 74.37 79.84 84.44 96.06
96.74 89.30 94.26 97.22 48.52 61.62 95.68 85.80
;
```

You can display the data by using the following statements, which produce [Output 121.5.1](#):

```
proc print data=auc;
run;
```

**Output 121.5.1** AUC Data for Test and Reference Drugs

Obs	TestAUC	RefAUC
1	103.40	90.11
2	59.92	77.71
3	68.17	77.71
4	94.54	97.51
5	69.48	58.21
6	72.17	101.30
7	74.37	79.84
8	84.44	96.06
9	96.74	89.30
10	94.26	97.22
11	48.52	61.62
12	95.68	85.80

The TestAUC and RefAUC variables represent the AUC measurements for each subject under the Test and Reference drugs, respectively. Use the following SAS statements to perform the equivalence analysis:

```
ods graphics on;

proc ttest data=auc dist=lognormal tost(0.8, 1.25);
  paired TestAUC*RefAUC;
run;

ods graphics off;
```

The **DIST=LOGNORMAL** option specifies the lognormal distributional assumption and requests an analysis in terms of geometric mean and coefficient of variation. The **TOST** option specifies the equivalence bounds 0.8 and 1.25.

[Output 121.5.2](#) shows basic summary statistics for the ratio of TestAUC to RefAUC.

**Output 121.5.2** Summary Statistics

#### The TTEST Procedure

**Ratio: TestAUC / RefAUC**

N	Geometric Mean	Coefficient of Variation	Minimum	Maximum
12	0.9412	0.1676	0.7124	1.1936

The geometric mean ratio of 0.9412 is the sample mean of the log-transformed data exponentiated to bring it back to the original scale. So the plasma concentration over the 20-hour period is slightly lower for the Test drug than for the Reference drug. The CV of 0.1676 is the ratio of the standard deviation to the (arithmetic) mean.

Output 121.5.3 shows the  $100(1 - \alpha)\% = 95\%$  confidence limits for the geometric mean ratio (0.8467 and 1.0462) and CV (0.1183 and 0.2884).

**Output 121.5.3** Confidence Limits

Geometric			Coefficient		
Mean	95% CL	Mean	of Variation	95% CL	CV
0.9412	0.8467	1.0462	0.1676	0.1183	0.2884

Output 121.5.4 shows the  $100(1 - 2\alpha)\% = 90\%$  confidence limits for the geometric mean ratio, 0.8634 and 1.0260.

**Output 121.5.4** Equivalence Limits

Geometric	Lower	90% CL		Upper	
Mean	Bound	Mean	Mean	Bound	Assessment
0.9412	0.8	< 0.8634	1.0260	< 1.25	Equivalent

The assessment of “Equivalent” reflects the fact that these limits are contained within the equivalence bounds 0.8 and 1.25. This result occurs if and only if the  $p$ -value of the test is less than the  $\alpha$  value specified in the ALPHA= option in the PROC TTEST statement, and it is the reason that  $100(1 - 2\alpha)\%$  confidence limits are shown in addition to the usual  $100(1 - \alpha)\%$  limits.

Output 121.5.5 shows the  $p$ -values for the two one-sided tests against the upper and lower equivalence bounds.

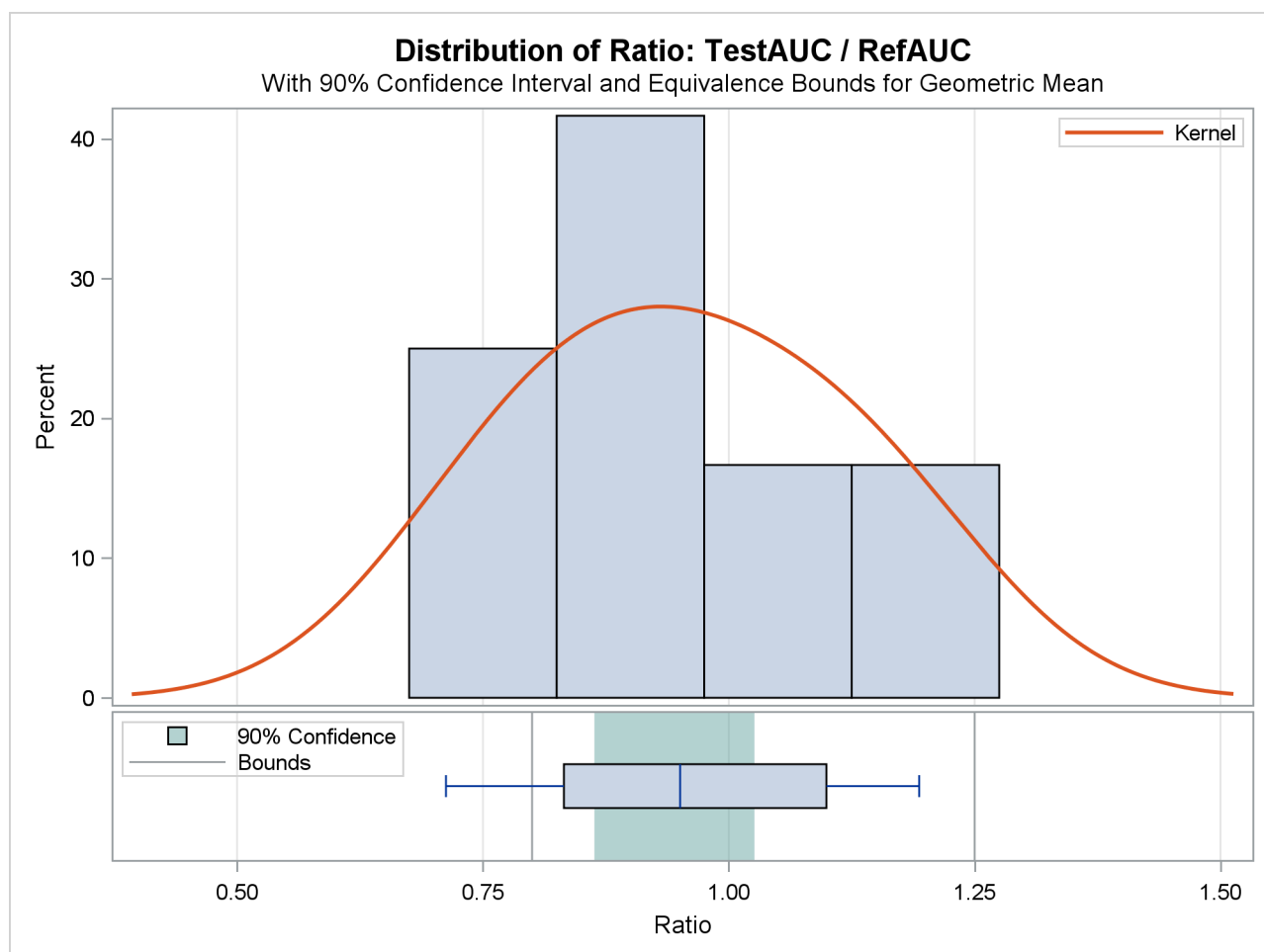
**Output 121.5.5** TOST Equivalence Test

Test	Null	DF	t Value	P-Value
Upper	0.8	11	3.38	0.0031
Lower	1.25	11	-5.90	<.0001
Overall				0.0031

The overall  $p$ -value of 0.0031, the larger of the two one-sided  $p$ -values, indicates significant evidence of equivalence between the Test and Reference drugs.

The summary panel in Output 121.5.6 shows a histogram, kernel density, box plot, and  $100(1 - 2\alpha)\% = 90\%$  confidence interval of the Test-to-Reference ratio of AUC, along with the equivalence bounds.

Output 121.5.6 Summary Panel

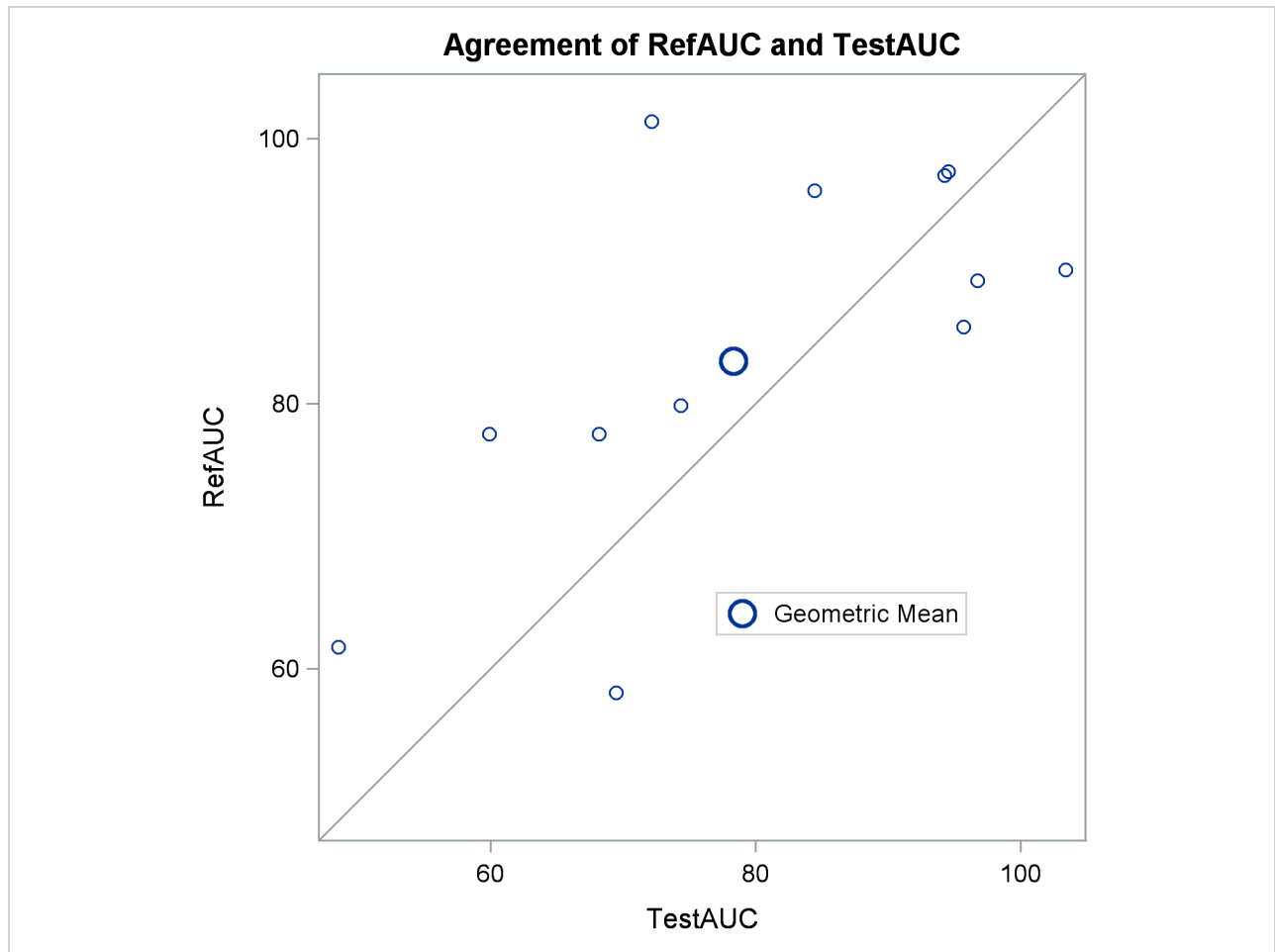


The confidence interval is closer to the lower equivalence bound than the upper bound and contained entirely within the bounds.

The agreement plot in [Output 121.5.7](#) reveals that the only four subjects with higher AUC for the Test drug are at the far lower or far upper end of the AUC distribution. This might merit further investigation.

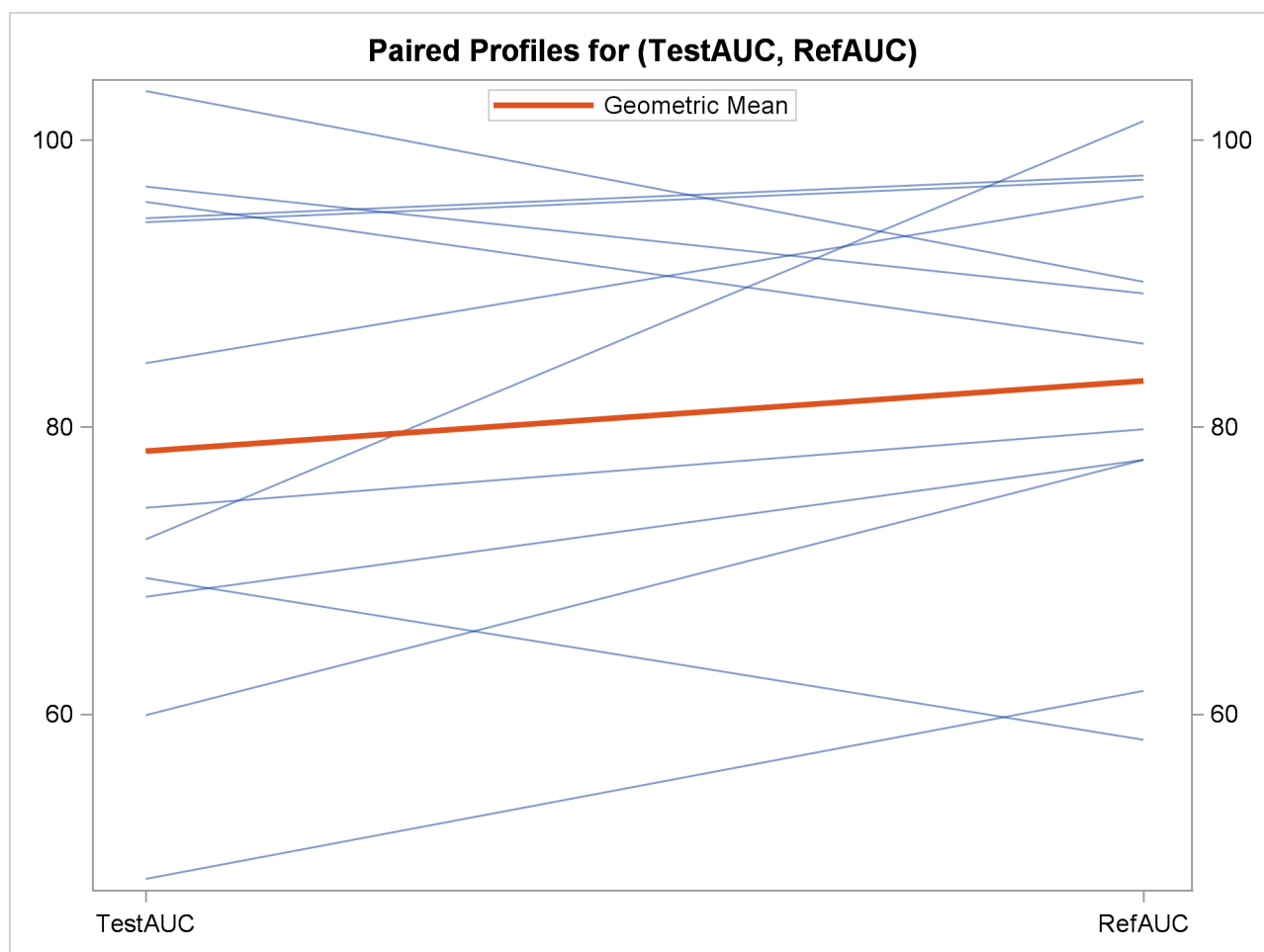


**Output 121.5.7** Agreement Plot



The profiles plot in [Output 121.5.8](#) is a different view of the same information contained in [Output 121.5.7](#), plotting the AUC from Test to Reference drug.

Output 121.5.8 Profiles Plot



## References

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# Subject Index

- AB/BA crossover
  - TTEST procedure, [9919](#)
- AB/BA crossover design
  - TTEST procedure, [9950](#)
- alpha level
  - TTEST procedure, [9910](#)
- analysis of variance, *see also* TTEST procedure
- Behrens-Fisher problem
  - TTEST procedure, [9927](#)
- Cochran and Cox  $t$  approximation
  - TTEST procedure, [9911](#), [9927](#)
- comparing
  - means (TTEST), [9902](#), [9940](#)
  - variances (TTEST), [9928](#), [9940](#)
- confidence intervals
  - TTEST procedure, [9911](#)
- crossover design
  - TTEST procedure, [9919](#), [9950](#)
- difference test
  - TTEST procedure, [9917](#)
- equality
  - of means (TTEST), [9902](#), [9940](#)
  - of variances (TTEST), [9928](#), [9940](#)
- equivalence test
  - TTEST procedure, [9917](#), [9959](#)
- folded form  $F$  statistic
  - TTEST procedure, [9928](#)
- graphics
  - TTEST procedure, [9936](#)
- hypothesis tests
  - parametric, comparing means (TTEST), [9902](#), [9940](#)
  - parametric, comparing variances (TTEST), [9928](#), [9940](#)
- lognormal distribution
  - TTEST procedure, [9911](#), [9959](#)
- lower one-sided  $t$  test
  - TTEST procedure, [9917](#)
- matched comparisons, *see* paired comparisons
- means, difference between
  - independent samples, [9902](#), [9940](#)
  - paired observations, [9902](#)
- means, ratio of
  - independent samples, [9902](#)
  - paired samples, [9902](#)
- normal distribution
  - TTEST procedure, [9911](#)
- ODS graph names
  - TTEST procedure, [9936](#)
- ODS Graphics
  - TTEST procedure, [9936](#)
- one-sample  $t$  test
  - TTEST procedure, [9902](#)
- one-sided  $t$  test
  - TTEST procedure, [9917](#)
- paired comparisons, [9945](#)
  - TTEST procedure, [9902](#)
- paired  $t$  test, [9918](#)
- paired-difference  $t$  test
  - TTEST procedure, [9902](#)
- paired-ratio  $t$  test
  - TTEST procedure, [9902](#)
- ratio test
  - TTEST procedure, [9917](#)
- Satterthwaite's approximation
  - TTEST procedure, [9927](#)
- statistical graphics
  - TTEST procedure, [9936](#)
- $t$  statistic
  - for equality of means, [9921](#)
- TOST equivalence test
  - TTEST procedure, [9917](#), [9959](#)
- TTEST procedure
  - AB/BA crossover, [9919](#)
  - AB/BA crossover design, [9950](#)
  - alpha level, [9910](#)
  - Behrens-Fisher problem, [9927](#)
  - Cochran and Cox  $t$  approximation, [9911](#), [9927](#)
  - computational methods, [9921](#)
  - confidence intervals, [9911](#)
  - crossover design, [9919](#), [9950](#)
  - difference test, [9917](#)
  - equivalence test, [9917](#), [9959](#)
  - folded form  $F$  statistic, [9928](#)

- graphics, 9936
- input data set, 9920
- introductory example, 9903
- lognormal distribution, 9911, 9959
- lower one-sided  $t$  test, 9917
- missing values, 9920
- normal distribution, 9911
- ODS graph names, 9936
- ODS Graphics, 9936
- ODS table names, 9936
- one-sided  $t$  test, 9917
- paired comparisons, 9902, 9945
- paired  $t$  test, 9918
- ratio test, 9917
- Satterthwaite's approximation, 9927
- statistical graphics, 9936
- TOST equivalence test, 9917, 9959
- two-sided  $t$  test, 9917
- uniformly most powerful unbiased test, 9923
- upper one-sided  $t$  test, 9917
- two-sample  $t$  test, 9940
  - TTEST procedure, 9902
- two-sided  $t$  test
  - TTEST procedure, 9917
- uniformly most powerful unbiased test
  - TTEST procedure, 9923
- upper one-sided  $t$  test
  - TTEST procedure, 9917
- variances
  - ratio of, 9940
  - ratio of (TTEST), 9928

# Syntax Index

ALPHA= option  
PROC TTEST statement, 9910

BY statement  
TTEST procedure, 9917

BYVAR option  
PROC TTEST statement, 9910

CI= option  
PROC TTEST statement, 9911

CLASS statement  
TTEST procedure, 9918

COCHRAN option  
PROC TTEST statement, 9911

CROSSOVER= option  
PROC TTEST statement, 9919

DATA= option  
PROC TTEST statement, 9911

DIST= option  
PROC TTEST statement, 9911

FREQ statement  
TTEST procedure, 9918

H0= option  
PROC TTEST statement, 9911

IGNOREPERIOD option  
PROC TTEST statement, 9919

NOBYVAR option  
PROC TTEST statement, 9912

ORDER= option  
PROC TTEST statement, 9912

PAIRED statement  
TTEST procedure, 9918

PLOTS option  
PROC TTEST statement, 9912

PROC TTEST  
See TTEST procedure, 9910

SIDES= option  
PROC TTEST statement, 9917

TEST= option  
PROC TTEST statement, 9917

TOST option

PROC TTEST statement, 9917

TTEST procedure  
syntax, 9909

TTEST procedure, BY statement, 9917

TTEST procedure, CLASS statement, 9918

TTEST procedure, FREQ statement, 9918

TTEST procedure, PAIRED statement, 9918

TTEST procedure, PROC TTEST statement, 9910

ALPHA= option, 9910

BYVAR option, 9910

CI= option, 9911

COCHRAN option, 9911

CROSSOVER= option, 9919

DATA= option, 9911

DIST= option, 9911

H0= option, 9911

IGNOREPERIOD option, 9919

NOBYVAR option, 9912

ORDER= option, 9912

PLOTS option, 9912

SIDES= option, 9917

TEST= option, 9917

TOST option, 9917

TTEST procedure, VAR statement, 9919

TTEST procedure, WEIGHT statement, 9920

VAR statement

TTEST procedure, 9919

WEIGHT statement

TTEST procedure, 9920