

ciwidth twomeans — Precision analysis for a two-means-difference CI

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Description

`ciwidth twomeans` computes sample size, CI width, and probability of CI width for a CI for a difference between two means from independent samples. It can compute sample size for a given CI width and probability of CI width. Alternatively, it can compute CI width for a given sample size and probability of CI width. It can also compute probability of CI width for a given sample size and CI width. Also see [\[PSS-3\] ciwidth](#) for PrSS analysis for other CI methods.

For power and sample-size analysis for a two-sample mean test, see [\[PSS-2\] power twomeans](#).

Quick start

Sample size required for a two-sided 95% CI for the difference between two means to have a width no larger than 12 with a probability of 90%, assuming a common standard deviation of 9

```
ciwidth twomeans, width(12) probwidth(0.9) sd(9)
```

Same as above, but for an upper one-sided CI

```
ciwidth twomeans, width(12) probwidth(0.9) sd(9) upper
```

Sample size required for a two-sided 95% CI for the difference between two means to have a width no larger than 12, with known control- and experimental-group standard deviations of 7 and 10, respectively

```
ciwidth twomeans, width(12) sd1(7) sd2(10) knownsds
```

CI width for a total sample size of 74 with balanced group sizes, given a 90% probability that the CI width will be no larger than the estimated value

```
ciwidth twomeans, n(74) probwidth(0.9) sd(9)
```

Same as above, but for sample sizes of 45 and 30 in groups 1 and 2, respectively

```
ciwidth twomeans, n1(45) n2(30) probwidth(0.9) sd(9)
```

Probability that the CI width is no larger than 12 for a sample size of 50

```
ciwidth twomeans, width(12) n(50) sd(9)
```

Menu

Statistics > Power, precision, and sample size

Syntax

Compute sample size

```
ciwidth twomeans, width(numlist) probwidth(numlist) [options]
```

Compute CI width

```
ciwidth twomeans, probwidth(numlist) n(numlist) [options]
```

Compute probability of CI width

```
ciwidth twomeans, width(numlist) n(numlist) [options]
```

| <i>options</i> | Description |
|---------------------------------------|--|
| Main | |
| * <u>l</u> evel(<i>numlist</i>) | confidence level; default is level(95) |
| * <u>a</u> lpha(<i>numlist</i>) | significance level; default is alpha(0.05) |
| * <u>p</u> robwidth(<i>numlist</i>) | probability of CI width; required to compute sample size and CI width |
| * <u>w</u> idth(<i>numlist</i>) | CI width; required to compute sample size and probability of CI width |
| * n(<i>numlist</i>) | total sample size; required to compute CI width and probability of CI width |
| * n1(<i>numlist</i>) | sample size of the control group |
| * n2(<i>numlist</i>) | sample size of the experimental group |
| * <u>n</u> ratio(<i>numlist</i>) | ratio of sample sizes, N2/N1; default is nratio(1), meaning equal group sizes |
| compute(N1 N2) | solve for N1 given N2 or for N2 given N1 |
| <u>n</u> fractional | allow fractional sample sizes |
| * <u>s</u> d(<i>numlist</i>) | common standard deviation of the control and the experimental groups assuming equal standard deviations in both groups; default is sd(1) |
| * sd1(<i>numlist</i>) | standard deviation of the control group; requires sd2() and knowsds |
| * sd2(<i>numlist</i>) | standard deviation of the experimental group; requires sd1() and knowsds |
| knownsds | request computation assuming known standard deviations for both groups; default is to assume unknown standard deviations |
| lower | lower one-sided CI; default is two-sided CI |
| upper | upper one-sided CI; default is two-sided CI |
| <u>o</u> nesided | synonym for option upper |
| <u>p</u> arallel | treat number lists in starred options or in command arguments as parallel when multiple values per option or argument are specified (do not enumerate all possible combinations of values) |

| | |
|---|--|
| Table | |
| <code>[no]table [(tablespec)]</code> | suppress table or display results as a table; see [PSS-3] ciwidth, table |
| <code>saving(filename [, replace])</code> | save the table data to <i>filename</i> ; use <code>replace</code> to overwrite existing <i>filename</i> |
| Graph | |
| <code>graph [(graphopts)]</code> | graph results; see [PSS-3] ciwidth, graph |
| Iteration | |
| <code>init(#)</code> | initial value for sample size; default is to use a closed-form normal approximation |
| <code>iterate(#)</code> | maximum number of iterations; default is <code>iterate(500)</code> |
| <code>tolerance(#)</code> | parameter tolerance; default is <code>tolerance(1e-12)</code> |
| <code>ftolerance(#)</code> | function tolerance; default is <code>ftolerance(1e-12)</code> |
| <code>[no]log</code> | suppress or display iteration log |
| <code>[no]dots</code> | suppress or display iterations as dots |
| <code>notitle</code> | suppress the title |

*Specifying a list of values in at least two starred options, or at least two command arguments, or at least one starred option and one argument results in computations for all possible combinations of the values; see [U] 11.1.8 **numlist**. Also see the `parallel` option.

`collect` is allowed; see [U] 11.1.10 **Prefix commands**.

`notitle` does not appear in the dialog box.

where *tablespec* is

```
column[:label] [column[:label] [...]] [ , tableopts ]
```

column is one of the columns defined below, and *label* is a column label (may contain quotes and compound quotes).

| <i>column</i> | Description | Symbol |
|-----------------------|--|-------------------|
| <code>level</code> | confidence level | $100(1 - \alpha)$ |
| <code>alpha</code> | significance level | α |
| <code>N</code> | total number of subjects | N |
| <code>N1</code> | number of subjects in the control group | N_1 |
| <code>N2</code> | number of subjects in the experimental group | N_2 |
| <code>nratio</code> | ratio of sample sizes, experimental to control | N_2/N_1 |
| <code>Pr_width</code> | probability of CI width | p_{width} |
| <code>width</code> | CI width | w |
| <code>sd</code> | common standard deviation | σ |
| <code>sd1</code> | control-group standard deviation | σ_1 |
| <code>sd2</code> | experimental-group standard deviation | σ_2 |
| <code>_all</code> | display all supported columns | |

Column `alpha` is shown in the default table in place of column `level` if `alpha()` is specified.

Columns `nratio`, `sd`, `sd1`, and `sd2` are shown in the default table if the corresponding options are specified.

Options

Main

`level()`, `alpha()`, `probwidth()`, `width()`, `n()`, `n1()`, `n2()`, `nratio()`, `compute()`, `nfractional`; see [PSS-3] **ciwidth**. `probwidth()` may not be combined with `sd1()`, `sd2()`, and `knownsds`.

`sd(numlist)` specifies the common standard deviation of the control and the experimental groups assuming equal standard deviations in both groups. The default is `sd(1)`.

`sd1(numlist)` specifies the standard deviation of the control group. If you specify `sd1()`, you must also specify `sd2()` and `knownsds`. `sd1()` may not be combined with `probwidth()`.

`sd2(numlist)` specifies the standard deviation of the experimental group. If you specify `sd2()`, you must also specify `sd1()` and `knownsds`. `sd2()` may not be combined with `probwidth()`.

`knownsds` requests that standard deviations of each group be treated as known in the computation. By default, standard deviations are treated as unknown, and the computation is performed for a Student's *t*-based CI. If `knownsds` is specified, the computation is performed for a normal-based CI. `knownsds` may not be combined with `probwidth()` and is not allowed when computing the probability of CI width.

`lower`, `upper`, `onesided`, `parallel`; see [PSS-3] **ciwidth**.

Table

`table`, `table()`, `notable`; see [PSS-3] **ciwidth, table**.

`saving()`; see [PSS-3] **ciwidth**.

Graph

`graph`, `graph()`; see [PSS-3] **ciwidth, graph**. Also see the *column* table for a list of symbols used by the graphs.

Iteration

`init(#)` specifies the initial value for the estimated sample size for sample-size determination. The estimated sample size is either the control-group size n_1 or, if `compute(N2)` is specified, the experimental-group size n_2 . The default is to use a closed-form normal approximation to compute an initial sample size.

`iterate()`, `tolerance()`, `ftolerance()`, `log`, `nolog`, `dots`, `nodots`; see [PSS-3] **ciwidth**.

The following option is available with `ciwidth twomeans` but is not shown in the dialog box:

`notitle`; see [PSS-3] **ciwidth**.

Remarks and examples

[stata.com](http://www.stata.com)

Remarks are presented under the following headings:

- Introduction*
- Using ciwidth twomeans*
- Computing sample size*
- Computing CI width*
- Computing probability of CI width*

This entry describes the `ciwidth twomeans` command and the methodology for PrSS analysis for a CI for a difference between two means from independent samples. See [PSS-3] [Intro \(ciwidth\)](#) for a general introduction to PrSS analysis, and see [PSS-3] [ciwidth](#) for a general introduction to the `ciwidth` command. For PSS analysis for hypothesis tests, see [PSS-2] [power](#).

Introduction

The analysis of means is one of the most commonly used approaches in many statistical studies. Many applications lead to the study of two independent means, such as studies comparing the average mileage of foreign and domestic cars, the average SAT scores obtained from two different coaching classes, the average yields of a crop using two different fertilizers, and so on. The two populations of interest are assumed to be independent. We are interested in a CI for the difference $\mu_D = \mu_2 - \mu_1$ between the two means μ_2 and μ_1 . The wider the ranges of the CI are, the less precise it is.

The precision of a CI is commonly measured by its width w or, for a symmetric CI such as the CI for the mean difference, by its half-width d , also known as the margin of error. For example, a two-sided two-means-difference CI is formed as $[\hat{\mu}_D - d, \hat{\mu}_D + d]$, where $\hat{\mu}_D$ is the point estimate of the mean difference. The CI width, the distance between the upper and lower limits, is $w = 2d$; it does not depend on the means difference estimate. The smaller the d or w the more precise the CI.

In PrSS analysis, it is usually of interest to determine the sample size that would be sufficient for a CI to have a prespecified width in a future study. Generally, larger sample sizes lead to more precise CIs. To compute the required sample size, we need to know the expression for w . The expression for w depends on various assumptions.

Similarly to the width of a [one-mean CI](#), the CI width w of a two-means-difference CI depends on sample estimates of standard deviations, in the case of unknown standard deviations. Therefore, w will vary from one sample to another. To ensure that a CI has the desired width in a future study, this sampling variability of w must be accounted for when computing the required sample size. [Kupper and Hafner \(1989\)](#) introduce what we call the probability of CI width, which specifies the probability of a future CI to have the width of no larger than some prespecified CI width for a given sample size. See [Methods and formulas](#) for details.

You can use `ciwidth twomeans` to perform PrSS analysis for a CI for the difference between two independent means. We discuss the command details in the next section.

Using ciwidth twomeans

`ciwidth twomeans` computes sample size, CI width, or probability of CI width for a two-means-difference CI. By default, a two-sided CI is assumed, and the confidence level is set to 95%. You may change the confidence level by specifying the `level()` option. Alternatively, you can specify the significance level in the `alpha()` option. You can specify the `upper` and `lower` options to request upper and lower one-sided CIs. By default, all computations assume a balanced- or equal-allocation design; see [PSS-4] [Unbalanced designs](#) for a description of how to specify an unbalanced design.

To compute total sample size, you must specify the CI width in the `width()` option and the probability of CI width in the `probwidth()` option. To compute CI width, you must specify the sample size in the `n()` option and the probability of CI width in the `probwidth()` option. You can also compute the probability of CI width given the sample size in `n()` and CI width in `width()`.

Instead of the total sample size, you can compute one of the group sizes given the other one. To compute the control-group sample size, you must specify the `compute(N1)` option and the sample size of the experimental group in the `n2()` option. Likewise, to compute the experimental-group sample size, you must specify the `compute(N2)` option and the sample size of the control group in the `n1()` option.

For CIs for means, the CI width does not depend on the mean point estimates, the sample means, so they are not needed in the computations.

By default, all computations are performed for a two-sample CI that assumes equal and unknown standard deviations. By default, the common standard deviation is set to one but may be changed by specifying the `sd()` option. To specify a known common standard deviation, use the `knownsds` option. To specify different standard deviations, use the respective `sd1()` and `sd2()` options. These options must be specified together and in combination with `knownsds`; they may not be used in combination with `sd()`. When `sd1()` and `sd2()` are specified, the computations are based on a normal z -based CI. The `sd1()`, `sd2()`, and `knownsds` options may not be combined with `probwidth()`.

Instead of the total sample size `n()`, you can specify individual group sizes in `n1()` and `n2()`, or specify one of the group sizes and `nratio()` when computing CI width or effect size. Also see *Two samples* in [PSS-4] **Unbalanced designs** for more details.

By default, the computed sample size is rounded up. You can specify the `nfractional` option to see the corresponding fractional sample size; see *Fractional sample sizes* in [PSS-4] **Unbalanced designs** for an example. The `nfractional` option is allowed only for sample-size determination.

Some of `ciwidth twomeans`'s computations require iteration. For example, when standard deviations are equal but unknown, the sample-size computation requires iteration. The default initial value of the estimated sample size is obtained by using a closed-form normal approximation. It may be changed by specifying the `init()` option. See [PSS-3] **ciwidth** for the descriptions of other options that control the iteration procedure.

In the following sections, we describe the use of `ciwidth twomeans` accompanied by examples for computing sample size, CI width, and probability of CI width.

Computing sample size

To compute the sample size required for a two-means-difference CI to have the width no larger than a target width, you must specify the target CI width in the `width()` option and the desired probability of achieving the target CI width in the `probwidth()` option.

► Example 1: Sample size for a two-means-difference CI

Similarly to the study in [PSS-2] **power twomeans**, we want to investigate the effects of smoking on lung function of males. In that entry, we tested the means of the forced expiratory volume (FEV), measured in liters (L), across smokers and nonsmokers, where better lung function implied higher values of FEV. Here, we wish to estimate the CI for the difference between the mean FEV of the two groups.

We are designing a new study for this objective, and we wish to find out how many subjects we need to enroll so that the width of a two-sided 95% CI for the mean FEV difference is no larger than 0.5 L with a probability of 0.96.

Assuming equal numbers of subjects in each group and a common standard deviation of 1, we compute the required sample size:

```
. ciwidth twomeans, probwidth(0.96) width(0.5)
Performing iteration ...
Estimated sample sizes for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
Study parameters:
      level =      95.00
      Pr_width =    0.9600
      width =    0.5000
      sd =    1.0000
Estimated sample sizes:
      N =      286
      N per group =    143
```

We need a total sample of 286 subjects, 143 per group.

The default computation is for the case of equal and unknown standard deviations, as indicated by the output. You can specify the `knownsds` option to request the computation assuming known standard deviations, but note that `knownsds` cannot be used in conjunction with `probwidth()`.

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▷ Example 2: Computing one of the group sizes

Suppose we anticipate a sample of 120 nonsmoking subjects. We wish to compute the required number of subjects in the smoking group, leaving all other study parameters unchanged from [example 1](#). We specify the number of subjects in the nonsmoking group in the `n1()` option and specify the `compute(N2)` option.

```
. ciwidth twomeans, probwidth(0.96) width(0.5) n1(120) compute(N2)
Performing iteration ...
Estimated sample sizes for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
Study parameters:
      level =      95.00
      Pr_width =    0.9600
      width =    0.5000
      sd =    1.0000
      N1 =      120
Estimated sample sizes:
      N =      296
      N2 =      176
```

We need a sample of 176 smoking subjects given a sample of 120 nonsmoking subjects.

◀

▷ Example 3: Unbalanced design

By default, `ciwidth twomeans` computes sample size for a balanced- or equal-allocation design. If we know the allocation ratio of subjects between the groups, we can compute the required sample size for an unbalanced design by specifying the `nratio()` option.

Continuing with [example 1](#), suppose that we anticipate on recruiting twice as many smokers as nonsmokers; that is, $n_2/n_1 = 2$. We specify the `nratio(2)` option to compute the required sample size for the specified unbalanced design.

```
. ciwidth twomeans, probwidth(0.96) width(0.5) nratio(2)
Performing iteration ...
Estimated sample sizes for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
Study parameters:
    level =    95.00
   Pr_width =  0.9600
    width =  0.5000
     sd =  1.0000
    N2/N1 =  2.0000
Estimated sample sizes:
     N =    321
    N1 =    107
    N2 =    214
```

We need a total sample size of 321 subjects, which is larger than the required total sample size for the corresponding balanced design from [example 1](#).

Also see [Two-samples](#) in [\[PSS-4\] Unbalanced designs](#) for more examples of unbalanced designs.



Computing CI width

To compute the CI width, you must specify the sample size in the `n()` option and the desired probability of achieving the target CI width in the `probwidth()` option.

► Example 4: Computing CI width for a two-means-difference CI

Suppose that we have enough resources to enroll 250 subjects in our study on FEV across smokers and nonsmokers. Further suppose that we would like to be 96% certain that the width of a future CI for this sample size will be no larger than the value we estimate. Given these parameters, we compute the CI width as follows:

```
. ciwidth twomeans, probwidth(0.96) n(250)
Estimated width for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
Study parameters:
    level =    95.00
     N =    250
N per group =  125
   Pr_width =  0.9600
     sd =  1.0000
Estimated width:
    width =  0.5373
```

The estimated width for a future two-sided 95% CI for the mean difference between the smoking and nonsmoking groups is 0.54, given other parameters.



Computing probability of CI width

To compute the probability that the width of a future CI will be no larger than the specified width, you must specify the sample size in the `n()` option and the target CI width in the `width()` option.

► Example 5: Computing probability of CI width for a two-means-difference CI

Continuing with [example 1](#), suppose that we have only enough resources to enroll a total of 250 subjects, instead of the 286 we computed before. Assuming equal-sized groups, and given this smaller sample size, we would like to know the probability of obtaining the target CI width of 0.5 for a two-sided 95% CI:

```
. ciwidth twomeans, width(0.5) n(250)
Estimated probability of width for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
Study parameters:
      level =      95.00
           N =       250
  N per group =     125
      width =     0.5000
           sd =     1.0000
Estimated probability of width:
      Pr_width =     0.5427
```

The estimated probability, given the total sample size of 250, is 54% and is rather low.

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► Example 6: Multiple values of study parameters

As a variation of [example 5](#), we would like to see how increasing the sample size, from the 250 we specified above, affects the probability of achieving a target CI width of 0.5. We compute the probability of CI width for a range of sample sizes between 250 and 300, with the step size of 10, by specifying the corresponding numlist in the `n()` option.

```
. ciwidth twomeans, width(0.5) n(250(10)300)
Estimated probability of width for a two-means-difference CI
Student's t two-sided CI assuming sd1 = sd2 = sd
```

| level | N | N1 | N2 | Pr_width | width | sd |
|-------|-----|-----|-----|----------|-------|----|
| 95 | 250 | 125 | 125 | .5427 | .5 | 1 |
| 95 | 260 | 130 | 130 | .7129 | .5 | 1 |
| 95 | 270 | 135 | 135 | .8467 | .5 | 1 |
| 95 | 280 | 140 | 140 | .9316 | .5 | 1 |
| 95 | 290 | 145 | 145 | .9749 | .5 | 1 |
| 95 | 300 | 150 | 150 | .9925 | .5 | 1 |

Assuming a balanced design, the probability of CI width increases from 54% to 99% as the sample size increases from 250 to 300, given a target CI width of 0.5.

For multiple values of parameters, the results are automatically displayed in a table, as we see above. For more examples of tables, see [\[PSS-3\] ciwidth, table](#). If you wish to produce sample-size and other curves, see [\[PSS-3\] ciwidth, graph](#).

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▷ Example 7: One-sided CI

By default, `ciwidth twomeans` performs computations based on a two-sided CI. You can specify the `upper` or `lower` option to request either an upper or lower one-sided CI.

Suppose we want to know the probability of achieving a smaller target CI width of 0.25 for an upper one-sided 95% CI for the difference between FEV means, given a smaller sample size of 200.

```
. ciwidth twomeans, width(0.25) n(200) upper
Estimated probability of width for a two-means-difference CI
Student's t upper CI assuming sd1 = sd2 = sd
Study parameters:
      level =      95.00
         N =       200
N per group =       100
      width =      0.2500
         sd =      1.0000
Estimated probability of width:
      Pr_width =      0.9199
```

Given a total sample size of 200, we are 92% likely to obtain an upper one-sided 95% CI with the width no larger than 0.25 in a future study.

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Stored results

`ciwidth twomeans` stores the following in `r()`:

Scalars

| | |
|-----------------------------|--|
| <code>r(level)</code> | confidence level |
| <code>r(alpha)</code> | significance level |
| <code>r(N)</code> | total sample size |
| <code>r(N_a)</code> | actual sample size |
| <code>r(N1)</code> | sample size of the control group |
| <code>r(N2)</code> | sample size of the experimental group |
| <code>r(nratio)</code> | ratio of sample sizes, $N2/N1$ |
| <code>r(nratio_a)</code> | actual ratio of sample sizes |
| <code>r(nfractional)</code> | 1 if <code>nfractional</code> is specified, 0 otherwise |
| <code>r(onesided)</code> | 1 for a one-sided CI, 0 otherwise |
| <code>r(Pr_width)</code> | probability of CI width |
| <code>r(Pr_width_a)</code> | actual probability of CI width (for sample-size determination when <code>probwidth()</code> specified) |
| <code>r(width)</code> | CI width |
| <code>r(width_a)</code> | actual CI width (for sample-size determination when <code>knownsds</code> specified) |
| <code>r(sd)</code> | common standard deviation of the control and experimental groups |
| <code>r(sd1)</code> | standard deviation of the control group |
| <code>r(sd2)</code> | standard deviation of the experimental group |
| <code>r(knownsds)</code> | 1 if option <code>knownsds</code> is specified, 0 otherwise |
| <code>r(separator)</code> | number of lines between separator lines in the table |
| <code>r(divider)</code> | 1 if <code>divider</code> is requested in the table, 0 otherwise |
| <code>r(init)</code> | initial value for sample size |
| <code>r(maxiter)</code> | maximum number of iterations |
| <code>r(iter)</code> | number of iterations performed |
| <code>r(tolerance)</code> | requested parameter tolerance |
| <code>r(deltax)</code> | final parameter tolerance achieved |
| <code>r(ftolerance)</code> | requested distance of the objective function from zero |
| <code>r(function)</code> | final distance of the objective function from zero |
| <code>r(converged)</code> | 1 if iteration algorithm converged, 0 otherwise |

Macros

| | |
|----------------------------|-------------------------------------|
| <code>r(type)</code> | <code>ci</code> |
| <code>r(method)</code> | <code>twomeans</code> |
| <code>r(onesidedci)</code> | upper or lower (for a one-sided CI) |
| <code>r(columns)</code> | displayed table columns |
| <code>r(labels)</code> | table column labels |
| <code>r(widths)</code> | table column widths |
| <code>r(formats)</code> | table column formats |

Matrices

| | |
|---------------------------|------------------|
| <code>r(pss_table)</code> | table of results |
|---------------------------|------------------|

Methods and formulas

Consider two independent samples with n_1 subjects in the control group and n_2 subjects in the experimental group. Let $\mathbf{x}_1 = (x_{11}, \dots, x_{1n_1})$ be a random sample of size n_1 from a normal population with mean μ_1 and variance σ_1^2 . Let $\mathbf{x}_2 = (x_{21}, \dots, x_{2n_2})$ be a random sample of size n_2 from a normal population with mean μ_2 and variance σ_2^2 . We are interested in a CI for the mean difference $\mu_2 - \mu_1$ estimated using samples \mathbf{x}_1 and \mathbf{x}_2 . Let $\mathbf{x} = (\mathbf{x}_1, \mathbf{x}_2)$. A general two-sided CI is defined as $[ll(\mathbf{x}), ul(\mathbf{x})]$, a lower one-sided CI as $[ll(\mathbf{x}), \infty)$, and an upper one-sided CI as $(-\infty, ul(\mathbf{x})]$, where $ll(\mathbf{x}) = ll$ and $ul(\mathbf{x}) = ul$ are the respective lower and upper confidence limits. Let w be the CI width.

The sample means and variances for the two independent samples are

$$\bar{x}_1 = \frac{1}{n_1} \sum_{i=1}^{n_1} x_{1i} \quad \text{and} \quad s_1^2 = \frac{1}{n_1 - 1} \sum_{i=1}^{n_1} (x_{1i} - \bar{x}_1)^2$$

$$\bar{x}_2 = \frac{1}{n_2} \sum_{i=1}^{n_2} x_{2i} \quad \text{and} \quad s_2^2 = \frac{1}{n_2 - 1} \sum_{i=1}^{n_2} (x_{2i} - \bar{x}_2)^2$$

Let \bar{x}_D be the sample mean difference $\bar{x}_2 - \bar{x}_1$.

A two-sided CI for the means difference is constructed as

$$[\bar{x}_D - w/2, \bar{x}_D + w/2]$$

where $w/2$ is the half-width or margin of error.

Lower and upper one-sided CIs are

$$[\bar{x}_D - w, \infty)$$

$$(-\infty, \bar{x}_D + w]$$

We use the CI width w as our measure of CI precision. Let $100(1 - \alpha)\%$ denote the confidence level, where $0 \leq \alpha \leq 1$ is the corresponding [significance level](#).

Let $R = n_2/n_1$ denote the allocation ratio. Then $n_2 = R \times n_1$ and CI width can be viewed as a function of n_1 . Therefore, for sample-size determination, the control-group sample size n_1 is computed first. The experimental-group size n_2 is then computed as $R \times n_1$, and the total sample size is computed as $n = n_1 + n_2$. By default, sample sizes are rounded to integer values; see [Fractional sample sizes](#) in [PSS-4] [Unbalanced designs](#) for details.

PrSS analysis using `ciwidth twomeans` can be performed under three different assumptions: 1) population standard deviations are known and equal; 2) population standard deviations are known and unequal; and 3) population standard deviations are unknown but equal. We describe each case below.

The following formulas are based on Kupper and Hafner (1989), Ryan (2013), Dixon and Massey (1983), Zar (2010), and Chow et al. (2018).

Methods and formulas are presented under the following headings:

Known equal and unequal standard deviations
Unknown and equal standard deviations

Known equal and unequal standard deviations

Below we present formulas for the computations that assume unequal standard deviations. When standard deviations are equal, the corresponding formulas are special cases of the formulas below with $\sigma_1 = \sigma_2 = \sigma$.

Let σ_D denote the standard deviation of the difference between the two sample means. With known standard deviation, $\sigma_D = \sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2}$. The statistic

$$TS = \frac{\bar{x}_D - (\mu_2 - \mu_1)}{\sigma_D}$$

follows a normal distribution.

Let $z_{1-\alpha}$ be the $(1 - \alpha)$ th quantile of a standard normal distribution. Based on the normal distribution of z , the CIs are

$$\begin{cases} [\bar{x}_D - z_{1-\alpha/2}\sigma_D, \bar{x}_D + z_{1-\alpha/2}\sigma_D] & \text{for a two-sided CI} \\ [\bar{x}_D - z_{1-\alpha}\sigma_D, \infty) & \text{for a lower CI} \\ (-\infty, \bar{x}_D + z_{1-\alpha}\sigma_D] & \text{for an upper CI} \end{cases}$$

After expanding σ_D , the corresponding width w is

$$w = \begin{cases} 2z_{1-\alpha/2}\sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2} & \text{for a two-sided CI} \\ z_{1-\alpha}\sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2} & \text{for lower and upper one-sided CIs} \end{cases}$$

The control-group sample size n_1 is computed as follows:

$$n_1 = \begin{cases} 4 \left(\frac{z_{1-\alpha/2}}{w}\right)^2 \left(\sigma_1^2 + \frac{\sigma_2^2}{R}\right) & \text{for a two-sided CI} \\ \left(\frac{z_{1-\alpha}}{w}\right)^2 \left(\sigma_1^2 + \frac{\sigma_2^2}{R}\right) & \text{for lower and upper one-sided CIs} \end{cases} \quad (1)$$

If one of the group sizes is known, the other one is computed using the following formula. For example, for a two-sided CI, to compute n_1 given n_2 , we use the following formula:

$$n_1 = \frac{\sigma_1^2}{\left(\frac{w}{2z_{1-\alpha/2}}\right)^2 - \frac{\sigma_2^2}{n_2}} \quad (2)$$

Unknown and equal standard deviations

When the standard deviations of the control group and the experimental group are unknown and equal, the statistic

$$t = \frac{\bar{x}_D - (\mu_2 - \mu_1)}{s_D}$$

follows a Student's t distribution with ν degrees of freedom. The estimated standard deviation of the sample mean difference s_D is

$$s_D = s_p \sqrt{1/n_1 + 1/n_2}$$

where $s_p = \left\{ \sum_{i=1}^{n_1} (x_{1i} - \bar{x}_1)^2 + \sum_{i=1}^{n_2} (x_{2i} - \bar{x}_2)^2 \right\} / (n_1 + n_2 - 2)$ is the pooled-sample standard deviation.

The degrees of freedom ν is

$$\nu = n_1 + n_2 - 2$$

Let $t_{\nu, \alpha}$ denote the α th quantile of a Student's t distribution with ν degrees of freedom. The CIs are

$$\begin{cases} [\bar{x}_D - t_{\nu, 1-\alpha/2} s_D, \bar{x}_D + t_{\nu, 1-\alpha/2} s_D] & \text{for a two-sided CI} \\ [\bar{x}_D - t_{\nu, 1-\alpha} s_D, \infty) & \text{for a lower CI} \\ (-\infty, \bar{x}_D + t_{\nu, 1-\alpha} s_D] & \text{for an upper CI} \end{cases}$$

Similarly to the case of an [unknown standard deviation](#) for a one-mean CI, the CI width depends on the sample standard deviations. Using the fact that statistic $\nu s_D^2 / \sigma_D^2$ follows a χ^2 distribution with ν degrees of freedom, we can compute the probability that the CI width is no larger than a specified value w .

The probability of CI width is

$$\Pr(w) = \begin{cases} \chi_\nu^2 \left\{ \frac{\nu w^2}{4 t_{\nu, 1-\alpha/2}^2 \sigma^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} \right\} & \text{for a two-sided CI} \\ \chi_\nu^2 \left\{ \frac{\nu w^2}{t_{\nu, 1-\alpha}^2 \sigma^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} \right\} & \text{for lower and upper one-sided CIs} \end{cases} \quad (4)$$

where $\chi_\nu^2(\cdot)$ is the c.d.f. of a χ^2 distribution with ν degrees of freedom.

We can compute the desired CI width from (4):

$$w = \begin{cases} 2 t_{\nu, 1-\alpha/2} \sigma \sqrt{\frac{\chi_{\nu, \Pr(w)}^2}{\nu} \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} & \text{for a two-sided CI} \\ t_{\nu, 1-\alpha} \sigma \sqrt{\frac{\chi_{\nu, \Pr(w)}^2}{\nu} \left(\frac{1}{n_1} + \frac{1}{n_2} \right)} & \text{for lower and upper one-sided CIs} \end{cases} \quad (5)$$

where $\chi_{\nu, p}^2$ is the p th quantile of a χ^2 distribution with ν degrees of freedom.

We can solve for the sample sizes iteratively from (5) using initial values obtained from (1) and (2).

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Also see

- [PSS-3] **ciwidth** — Precision and sample-size analysis for CIs
- [PSS-3] **ciwidth, graph** — Graph results from the ciwidth command
- [PSS-3] **ciwidth, table** — Produce table of results from the ciwidth command
- [PSS-2] **power twomeans** — Power analysis for a two-sample means test
- [PSS-5] **Glossary**
- [R] **ttest** — t tests (mean-comparison tests)
- [R] **ztest** — z tests (mean-comparison tests, known variance)

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