

Chapter 277

Assurance for Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance

Introduction

This procedure calculates the assurance of non-inferiority two-sample t-tests in which the outcome is a continuous normal random variable and the variances of the two groups (populations) are assumed to be equal. The calculation is based on a user-specified prior distribution of the effect size parameters. This procedure may also be used to determine the needed sample size to obtain a specified assurance.

The methods for assurance calculation in this procedure are based on O'Hagan, Stevens, and Campbell (2005). Sample size formulas for non-inferiority tests of two means are presented in Chow et al. (2018) pages 50-51.

Assurance

The assurance of a design is the expected value of the power with respect to one or more prior distributions of the design parameters. Assurance is also referred to as *Bayesian assurance*, *expected power*, *average power*, *statistical assurance*, *hybrid classical-Bayesian procedure*, or *probability of success*.

The power of a design is the probability of rejecting the null hypothesis, conditional on a given set of design attributes, such as the test statistic, the significance level, the sample size, and the effect size to be detected. As the effect size parameters are typically unknown quantities, the stated power may be very different from the true power if the specified parameter values are inaccurate.

While power is conditional on individual design parameter values, and is highly sensitive to those values, assurance is the average power across a presumed prior distribution of the effect size parameters. Thus, assurance adds a Bayesian element to the frequentist framework, resulting in a hybrid approach to the probability of trial or study success. It should be noted that when it comes time to perform the statistical test on the resulting data, these methods for calculating assurance assume that the traditional (frequentist) tests will be used.

The next section describes some of the ways in which the prior distributions for effect size parameters may be determined.

Elicitation

In order to calculate assurance, a suitable prior distribution for the effect size parameters must be determined. This process is called the *elicitation* of the prior distribution.

The elicitation may be as simple as choosing a distribution that seems plausible for the parameter(s) of interest, or as complex as combining the informed advice of several experts based on experience in the field, available pilot data, or previous studies. The accuracy of the assurance value depends on the accuracy of the elicited prior distribution. The assumption (or hope) is that an informed prior distribution will produce a more accurate estimate of the probability of trial success than a single value estimate. Because clinical trials and other studies are often costly, many institutions now routinely require an elicitation step.

Two reference texts that focus on elicitation are O'Hagan, Buck, Daneshkhah, Eiser, Garthwaite, Jenkinson, Oakley, and Rakow (2006) and Dias, Morton, and Quigley (2018).

Non-Inferiority, Two-Sample T-Test

A *non-inferiority test* tests that the treatment mean is not worse than the reference mean by more than a non-inferiority margin. The actual direction of the hypothesis depends on the response variable being studied. The word *NIM* refers to the non-inferiority margin.

Case 1: High Values Good

In this case, higher values are better. The hypotheses are arranged so that rejecting the null hypothesis implies that the treatment mean is no less than a small amount below the reference mean. The value of δ at which power is calculated is often set to zero. The null and alternative hypotheses with $\delta_0 = -|NIM|$ are

$$\begin{array}{ll} H_0: \mu_1 \leq \mu_2 - |NIM| & \text{versus} \quad H_1: \mu_1 > \mu_2 - |NIM| \\ H_0: \mu_1 - \mu_2 \leq -|NIM| & \text{versus} \quad H_1: \mu_1 - \mu_2 > -|NIM| \\ H_0: \delta \leq -|NIM| & \text{versus} \quad H_1: \delta > -|NIM| \end{array}$$

Case 2: High Values Bad

In this case, lower values are better. The hypotheses are arranged so that rejecting the null hypothesis implies that the treatment mean is no more than a small amount above the reference mean. The value of δ at which power is calculated is often set to zero. The null and alternative hypotheses with $\delta_0 = |NIM|$ are

$$\begin{array}{ll} H_0: \mu_1 \geq \mu_2 + |NIM| & \text{versus} \quad H_1: \mu_1 < \mu_2 + |NIM| \\ H_0: \mu_1 - \mu_2 \geq |NIM| & \text{versus} \quad H_1: \mu_1 - \mu_2 < |NIM| \\ H_0: \delta \geq |NIM| & \text{versus} \quad H_1: \delta < |NIM| \end{array}$$

Test Statistic

Under the null hypothesis, this test assumes that the two groups of data are simple random samples from a single population of normally distributed values that all have the same mean and variance. This assumption implies that the data are continuous, and their distribution is symmetric. The calculation of the test statistic for the case when higher response values are better is as follows.

$$t_{df} = \frac{(\bar{X}_1 - \bar{X}_2) - \delta_0}{s_{\bar{X}_1 - \bar{X}_2}}$$

where

$$\bar{X}_k = \frac{\sum_{i=1}^{N_k} X_{ki}}{N_k},$$

$$s_k = \sqrt{\left(\frac{\sum_{i=1}^{N_k} (X_{ki} - \bar{X}_k)^2}{(N_k - 1)} \right)},$$

$$s_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2} \left(\frac{1}{N_1} + \frac{1}{N_2} \right)},$$

$$df = N_1 + N_2 - 2,$$

and δ_0 is the value of the difference hypothesized by the null hypothesis which depends on the magnitude and sign of NIM .

The null hypothesis is rejected if the computed p-value is less than a specified level (usually 0.05). Otherwise, no conclusion can be reached.

Power Calculation

The power is calculated from N_1 and N_2 , α , the assumed $\delta = \mu_1 - \mu_2$, and the assumed common standard deviation, $\sigma_1 = \sigma_2 = \sigma$.

The steps for calculating the power are as follows:

1. Find t_α such that $1 - T_{df}(t_\alpha) = \alpha$, where $T_{df}(x)$ is the area to the left of x under a central- t distribution with degrees of freedom, $df = N_1 + N_2 - 2$.
2. Calculate: $\sigma_{\bar{X}} = \sigma \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$.
3. Calculate the noncentrality parameter: $\lambda = \frac{\delta - \delta_0}{\sigma_{\bar{X}}}$.
4. Calculate: $Power = 1 - T'_{df,\lambda}(t_\alpha)$, where $T'_{df,\lambda}(x)$ is the area to the left of x under a noncentral- t distribution with degrees of freedom, $df = N_1 + N_2 - 2$, and noncentrality parameter, λ .

The algorithms for calculating power for the opposite direction is analogous to this method.

Assurance Calculation

This assurance computation described here is based on O'Hagan, Stevens, and Campbell (2005).

Let $P_1(H|\delta, \sigma)$ be the power function described above where H is the event that null hypothesis is rejected conditional on the values of the parameters. The specification of δ and σ is critical to the power calculation, but the actual values are seldom known. Assurance is defined as the expected power where the expectation is with respect to a joint prior distribution for the parameters δ and σ . Hence, the definition of assurance is

$$Assurance = E_{\delta, \sigma}(P_1(H|\delta, \sigma)) = \iint P_1(H|\delta, \sigma) f(\delta, \sigma) d\delta d\sigma$$

where $f(\delta, \sigma)$ is the joint prior distribution of δ and σ .

In **PASS**, the joint prior distribution can be specified as either a discrete approximation to the joint prior distribution, or as individual prior distributions, one for each parameter.

Specifying a Joint Prior Distribution

If the joint prior distribution is to be specified directly, the distribution is specified in **PASS** using a discrete approximation to the function $f(\delta, \sigma)$. This provides flexibility in specifying the joint prior distribution. In the two-parameter case, three columns are entered on the spreadsheet: two for the parameters and a third for the probability. Each row gives a value for each parameter and the corresponding parameter-combination probability. The accuracy of the distribution approximation is controlled by the number of points (spreadsheet rows) that are used.

An example of entering a joint prior distribution is included at the end of the chapter.

Specifying Individual Prior Distributions

Ciarleglio, Arendt, and Peduzzi (2016) suggest that more flexibility is available if the joint prior distribution is separated into two independent distributions as follows:

$$f(\delta, \sigma) = f_1(\delta)f_2(\sigma)$$

where $f_1(\delta)$ is the prior distribution of δ and $f_2(\sigma)$ is the prior distribution of σ . This method is also available in **PASS**. In this case, the definition of assurance becomes

$$Assurance = E_{\delta, \sigma}(P_1(H|\delta, \sigma)) = \iint P_1(H|\delta, \sigma) f_1(\delta) f_2(\sigma) d\delta d\sigma$$

Using this definition, the assurance can be calculated using numerical integration. There are a variety of pre-programmed, univariate prior distributions available in **PASS**.

Fixed Values (No Prior) and Custom Values

For any given parameter, **PASS** also provides the option of entering a single fixed value for the prior distribution, or a series of values and corresponding probabilities (using the spreadsheet), rather than one of the pre-programmed distributions.

Numerical Integration in PASS (and Notes on Computation Speed)

When the prior distribution is specified as independent univariate distributions, **PASS** uses a numerical integration algorithm to compute the assurance value as follows:

The domain of each prior distribution is divided into M intervals. Since many of the available prior distributions are unbounded on one (e.g., Gamma) or both (e.g., Normal) ends, an approximation is made to make the domain finite. This is accomplished by truncating the distribution to a domain between the two quantiles: $q_{0.001}$ and $q_{0.999}$.

The value of M controls the accuracy and speed of the algorithm. If only one parameter is to be given a prior distribution, then a value of M between 50 and 100 usually gives an accurate result in a timely manner. However, if two parameters are given priors, the number of iterations needed increases from M to M^2 . For example, if M is 100, 10000 iterations are needed. Reducing M from 100 to 50 reduces the number of iterations from 10000 to 2500.

The algorithm runtime increases when searching for sample size rather than solving for assurance, as a search algorithm is employed in this case. When solving for sample size, we recommend reducing M to 20 or less while exploring various scenarios, and then increasing M to 50 or more for a final, more accurate, result.

List of Available Univariate Prior Distributions

This section lists the univariate prior distributions that may be used for any of the applicable parameters when the Prior Entry Method is set to Individual.

No Prior

If 'No Prior' is chosen for a parameter, the parameter is assumed to take on a single, fixed value with probability one.

Beta (Shape 1, Shape 2, a, c)

A random variable X that follows the beta distribution is defined on a finite interval $[a, c]$. Two shape parameters (α and β) control the shape of this distribution. Two location parameters a and c give the minimum and maximum of X .

The probability density function of the beta distribution is

$$f(x|\alpha, \beta, a, c) = \frac{\left(\frac{x-a}{c-a}\right)^{\alpha-1} \left(\frac{c-x}{c-a}\right)^{\beta-1}}{(c-a)B(\alpha, \beta)}$$

where $B(\alpha, \beta) = \Gamma(\alpha) \Gamma(\beta) / \Gamma(\alpha + \beta)$ and $\Gamma(z)$ is the gamma function.

The mean of X is

$$\mu_X = \frac{\alpha c + \beta a}{\alpha + \beta}$$

Various distribution shapes are controlled by the values of α and β . These include

Symmetric and Unimodal

$$\alpha = \beta > 1$$

U Shaped

$$\alpha = \beta < 1$$

Bimodal

$$\alpha, \beta < 1$$

Uniform

$$\alpha = \beta = 1$$

Parabolic

$$\alpha = \beta = 2$$

Bell-Shaped

$$\alpha = \beta > 2$$

Gamma (Shape, Scale)

A random variable X that follows the gamma distribution is defined on the interval $(0, \infty)$. A shape parameter, κ , and a scale parameter, θ , control the distribution.

The probability density function of the gamma distribution is

$$f(x|\kappa, \theta) = \frac{x^{\kappa-1} e^{-\frac{x}{\theta}}}{\theta^{\kappa} \Gamma(\kappa)}$$

where $\Gamma(z)$ is the gamma function.

The mean of X is

$$\mu_X = \frac{\kappa}{\theta}$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(Min \leq X \leq Max)$ where Min and Max are two truncation bounds.

Inverse-Gamma (Shape, Scale)

A random variable X that follows the inverse-gamma distribution is defined on the interval $(0, \infty)$. If $Y \sim \text{gamma}$, then $X = 1 / Y \sim \text{inverse-gamma}$. A shape parameter, α , and a scale parameter, β , control the distribution.

The probability density function of the inverse-gamma distribution is

$$f(x|\alpha, \beta) = \frac{\beta^\alpha x^{\alpha-1} e^{-\frac{\beta}{x}}}{\Gamma(\alpha)}$$

where $\Gamma(z)$ is the gamma function.

The mean of X is

$$\mu_X = \frac{\beta}{\alpha - 1} \text{ for } \alpha > 1$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(Min \leq X \leq Max)$ where Min and Max are two truncation bounds.

Logistic (Location, Scale)

A random variable X that follows the logistic distribution is defined on the interval $(-\infty, \infty)$. A location parameter, μ , and a scale parameter, s , control the distribution.

The probability density function of the logistic distribution is

$$f(x|\mu, s) = \frac{e^{-\frac{x-\mu}{s}}}{s \left(1 + e^{-\frac{x-\mu}{s}}\right)^2}$$

The mean of X is

$$\mu_X = \mu$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(Min \leq X \leq Max)$ where Min and Max are two truncation bounds.

Lognormal (Mean, SD)

A random variable X that follows the lognormal distribution is defined on the interval $(0, \infty)$. A location parameter, $\mu_{\log(X)}$, and a scale parameter, $\sigma_{\log(X)}$, control the distribution. If $Z \sim$ standard normal, then $X = e^{\mu + \sigma Z} \sim$ lognormal. Note that $\mu_{\log(X)} = E(\log(X))$ and $\sigma_{\log(X)} = \text{Standard Deviation}(\log(X))$.

The probability density function of the lognormal distribution is

$$f(x|\mu, \sigma) = \frac{e^{-\frac{1}{2}\left(\frac{\log x - \mu}{\sigma}\right)^2}}{x\sigma\sqrt{2\pi}}$$

The mean of X is

$$\mu_X = e^{\mu + \frac{\sigma^2}{2}}$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(\text{Min} \leq X \leq \text{Max})$ where Min and Max are two truncation bounds.

LogT (Mean, SD)

A random variable X that follows the logT distribution is defined on the interval $(0, \infty)$. A location parameter, $\mu_{\log(X)}$, a scale parameter, $\sigma_{\log(X)}$, and a shape parameter, ν , control the distribution. Note that ν is referred to as the *degrees of freedom*.

If $t \sim$ Student's t , then $X = e^{\mu + \sigma t} \sim$ logT.

The probability density function of the logT distribution is

$$f(x|\mu, \sigma, \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{x\Gamma\left(\frac{\nu}{2}\right)\sigma\sqrt{\nu\pi}} \left(1 + \frac{1}{\nu}\left(\frac{\log x - \mu}{\sigma}\right)^2\right)^{-\left(\frac{\nu+1}{2}\right)}$$

The mean of X is not defined.

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(\text{Min} \leq X \leq \text{Max})$ where Min and Max are two truncation bounds.

Normal (Mean, SD)

A random variable X that follows the normal distribution is defined on the interval $(-\infty, \infty)$. A location parameter, μ , and a scale parameter, σ , control the distribution.

The probability density function of the normal distribution is

$$f(x|\mu, \sigma) = \frac{e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}}$$

The mean of X is

$$\mu_X = \mu$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(Min \leq X \leq Max)$ where Min and Max are two truncation bounds.

T (Mean, SD, DF)

A random variable X that follows Student's t distribution is defined on the interval $(-\infty, \infty)$. A location parameter, μ , a scale parameter, σ , and a shape parameter, ν , control the distribution. Note that ν is referred to as the *degrees of freedom* or *DF*.

The probability density function of the Student's t distribution is

$$f(x|\mu, \sigma, \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)\sigma\sqrt{\nu\pi}} \left(1 + \frac{1}{\nu}\left(\frac{x-\mu}{\sigma}\right)^2\right)^{\left(\frac{-\nu-1}{2}\right)}$$

The mean of X is μ if $\nu > 1$.

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(Min \leq X \leq Max)$ where Min and Max are two truncation bounds.

Triangle (Mode, Min, Max)

Let a = minimum, b = maximum, and c = mode. A random variable X that follows a triangle distribution is defined on the interval (a, b) .

The probability density function of the triangle distribution is

$$f(x|a, b, c) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)} & \text{for } a \leq x < c \\ \frac{2}{b-a} & \text{for } x = c \\ \frac{2(b-x)}{(b-a)(b-c)} & \text{for } c < x \leq b \end{cases}$$

The mean of X is

$$\frac{a + b + c}{3}$$

Uniform (Min, Max)

Let a = minimum and b = maximum. A random variable X that follows a uniform distribution is defined on the interval $[a, b]$.

The probability density function of the uniform distribution is

$$f(x|a, b) = \begin{cases} \frac{1}{b-a} & \text{for } a \leq x \leq b \end{cases}$$

The mean of X is

$$\frac{a + b}{2}$$

Weibull (Shape, Scale)

A random variable X that follows the Weibull distribution is defined on the interval $(0, \infty)$. A shape parameter, κ , and a scale parameter, λ , control the distribution.

The probability density function of the Weibull distribution is

$$f(x|\kappa, \lambda) = \frac{\kappa}{\lambda} \left(\frac{x}{\lambda}\right)^{\kappa-1} e^{-\left(\frac{x}{\lambda}\right)^\kappa}$$

The mean of X is

$$\mu_X = \kappa \Gamma\left(1 + \frac{1}{\kappa}\right)$$

A truncated version of the distribution is constructed by dividing the density by $1 - \text{Prob}(\text{Min} \leq X \leq \text{Max})$ where Min and Max are two truncation bounds.

Custom (Values and Probabilities in Spreadsheet)

This custom prior distribution is represented by a set of user-specified points and associated probabilities, entered in two columns of the spreadsheet. The points make up the entire set of values that are used for this parameter in the calculation of assurance. The associated probabilities should sum to one. Note that custom values and probabilities can be used to approximate any continuous distribution.

For example, a prior distribution of X might be

X_i	P_i
10	0.2
20	0.2
30	0.3
40	0.2
50	0.1

In this example, the mean of X is

$$\mu_X = \sum_{i=1}^5 X_i P_i$$

Example 1 – Assurance Over a Range of Sample Sizes

Suppose a test is to be conducted to determine if a new cancer treatment adversely affects bone density. The adjusted mean bone density (AMBD) in the population of interest is 0.002300 gm/cm with a standard deviation of 0.000300 gm/cm. Clinicians decide that if the treatment reduces AMBD by more than 5% (0.000115 gm/cm), it poses a significant health threat.

Following accepted procedure, the analysis will be a non-inferiority test using the t -test at the 0.025 significance level. Power is to be calculated assuming that the new treatment has no effect on AMBD. The researchers want to achieve a power of at least 90%. All numbers have been multiplied by 10000 to make the reports and plots easier to read. The required sample size is 144 per group (see Example 2 of the *Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance* procedure).

To complete their sample size study, the researchers want to run an assurance analysis for a range of group sample sizes from 50 to 300. An elicitation exercise determined that the prior distribution of the mean difference should be normal with mean 0.0 and standard deviation 0.5. The elicitation also concluded that prior distribution of the common group standard deviation should be a truncated-normal with mean 3, standard deviation 0.5, and left boundary 0.0001.

Setup

If the procedure window is not already open, use the PASS Home window to open it. The parameters for this example are listed below and are stored in the **Example 1** settings file. To load these settings to the procedure window, click **Open Example Settings File** in the Help Center or File menu.

Design Tab

Solve For	Assurance
Prior Entry Method	Individual (Enter a prior distribution for each applicable parameter)
Higher Means Are	Better (H1: $\delta > -NIM$)
Alpha	0.025
Group Allocation	Equal (N1 = N2)
Sample Size Per Group	50 100 144 150 200 250 300
NIM (Non-Inferiority Margin)	1.15
Prior Distribution of δ	Normal (Mean, SD)
Mean	0
SD	0.5
Truncation Boundaries	None
Prior Distribution of σ	Normal (Mean, SD)
Mean	3
SD	0.5
Truncation Boundaries	Left
Left Boundary	0.0001

Options Tab

Number of Computation Points for each	30
Prior Distribution	
Maximum N1 in Sample Size Search	5000

Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Reports

Numeric Results

Solve For: [Assurance](#)
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$
 Prior Type: Independent Univariate Distributions

Prior Distributions

δ : Normal (Mean = 0, SD = 0.5).
 σ : Normal (Mean = 3, SD = 0.5), Left Boundary = 0.0001.

Assurance*	Power‡	Sample Size			Non-Inferiority Margin -NIM	Expected Mean Difference $E(\delta)$	Expected Standard Deviation $E(\sigma)$	Alpha
		N1	N2	N				
0.49030	0.47524	50	50	100	-1.15	0	3	0.025
0.68421	0.76957	100	100	200	-1.15	0	3	0.025
0.76852	0.90004	144	144	288	-1.15	0	3	0.025
0.77683	0.91134	150	150	300	-1.15	0	3	0.025
0.82859	0.96885	200	200	400	-1.15	0	3	0.025
0.86087	0.98976	250	250	500	-1.15	0	3	0.025
0.88261	0.99681	300	300	600	-1.15	0	3	0.025

* The number of points used for computation of the prior(s) was 30.

‡ Power was calculated using $\delta = E(\delta) = 0$ and $\sigma = E(\sigma) = 3$.
 $= E(\delta) = 0$ and $\sigma = E(\sigma) = 3$.

Assurance	The expected power where the expectation is with respect to the prior distribution(s).
Power	The power calculated using the means of the prior distributions as the values of the corresponding parameters.
N1	The number of subjects in group 1.
N2	The number of subjects in group 2.
N	The total sample size. $N = N1 + N2$.
-NIM	The magnitude and direction of the margin of non-inferiority. Since higher means are better, this value is negative and is the distance below the reference mean that is still considered non-inferior.
$E(\delta)$	The expected value over its prior distribution of the difference in the group means assumed by the alternative hypothesis. Note that $\delta = \mu_1 - \mu_2$.
$E(\sigma)$	The expected value over its prior distribution of the standard deviation used for both groups.
Alpha	The probability of rejecting a true null hypothesis.

Summary Statements

A parallel two-group design will be used to test whether the Group 1 (treatment) mean (μ_1) is non-inferior to the Group 2 (control) mean (μ_2), with a non-inferiority margin of -1.15 ($H_0: \delta \leq -1.15$ versus $H_1: \delta > -1.15$, $\delta = \mu_1 - \mu_2$). The comparison will be made using a one-sided, two-sample, equal-variance t-test, with a Type I error rate (α) of 0.025. The prior distribution used for the mean difference is Normal (Mean = 0, SD = 0.5). The prior distribution used for the standard deviation is Normal (Mean = 3, SD = 0.5), Left Boundary = 0.0001. With sample sizes of 50 for Group 1 (treatment) and 50 for Group 2 (control), the assurance (average power) is 0.4903.

Assurance for Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance

Dropout-Inflated Sample Size

Dropout Rate	Sample Size			Dropout-Inflated Enrollment Sample Size			Expected Number of Dropouts		
	N1	N2	N	N1'	N2'	N'	D1	D2	D
20%	50	50	100	63	63	126	13	13	26
20%	100	100	200	125	125	250	25	25	50
20%	144	144	288	180	180	360	36	36	72
20%	150	150	300	188	188	376	38	38	76
20%	200	200	400	250	250	500	50	50	100
20%	250	250	500	313	313	626	63	63	126
20%	300	300	600	375	375	750	75	75	150

Dropout Rate	The percentage of subjects (or items) that are expected to be lost at random during the course of the study and for whom no response data will be collected (i.e., will be treated as "missing"). Abbreviated as DR.
N1, N2, and N	The evaluable sample sizes at which power is computed (as entered by the user). If N1 and N2 subjects are evaluated out of the N1' and N2' subjects that are enrolled in the study, the design will achieve the stated power.
N1', N2', and N'	The number of subjects that should be enrolled in the study in order to obtain N1, N2, and N evaluable subjects, based on the assumed dropout rate. N1' and N2' are calculated by inflating N1 and N2 using the formulas $N1' = N1 / (1 - DR)$ and $N2' = N2 / (1 - DR)$, with N1' and N2' always rounded up. (See Julious, S.A. (2010) pages 52-53, or Chow, S.C., Shao, J., Wang, H., and Lokhnygina, Y. (2018) pages 32-33.)
D1, D2, and D	The expected number of dropouts. $D1 = N1' - N1$, $D2 = N2' - N2$, and $D = D1 + D2$.

Dropout Summary Statements

Anticipating a 20% dropout rate, 63 subjects should be enrolled in Group 1, and 63 in Group 2, to obtain final group sample sizes of 50 and 50, respectively.

References

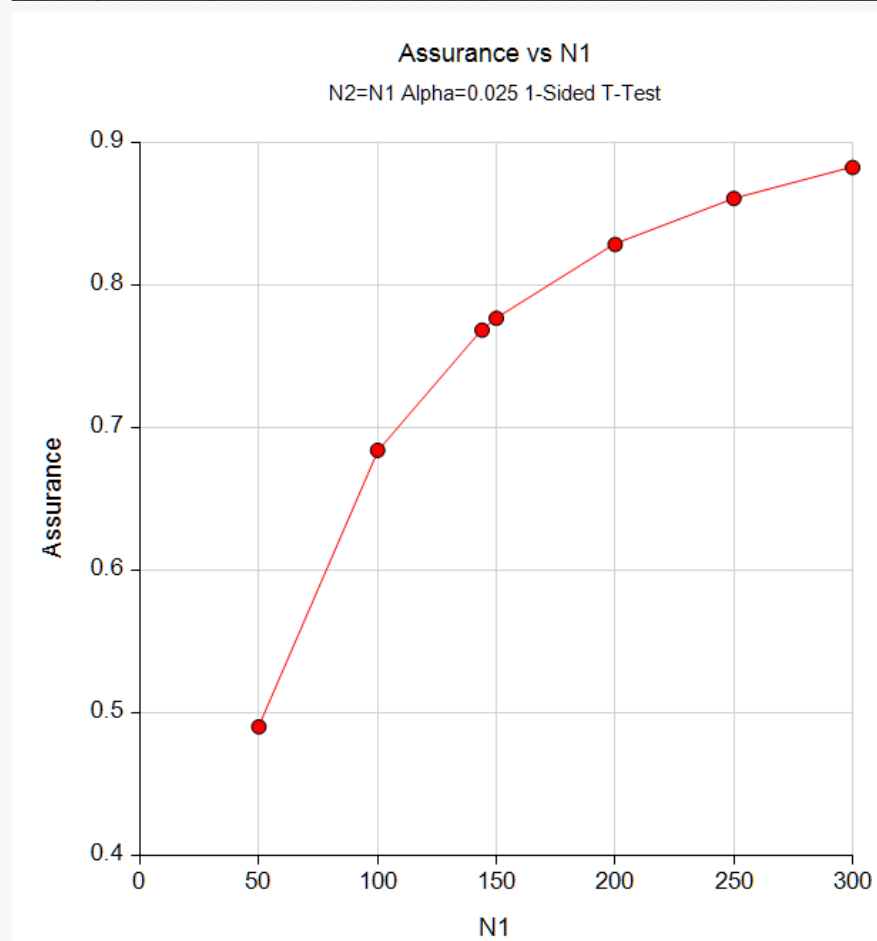
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This report shows the assurance values obtained by each sample size. Note that the assurance value at a sample size of 144, the size chosen in the power analysis, is 0.77.

Assurance for Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance

Plots Section

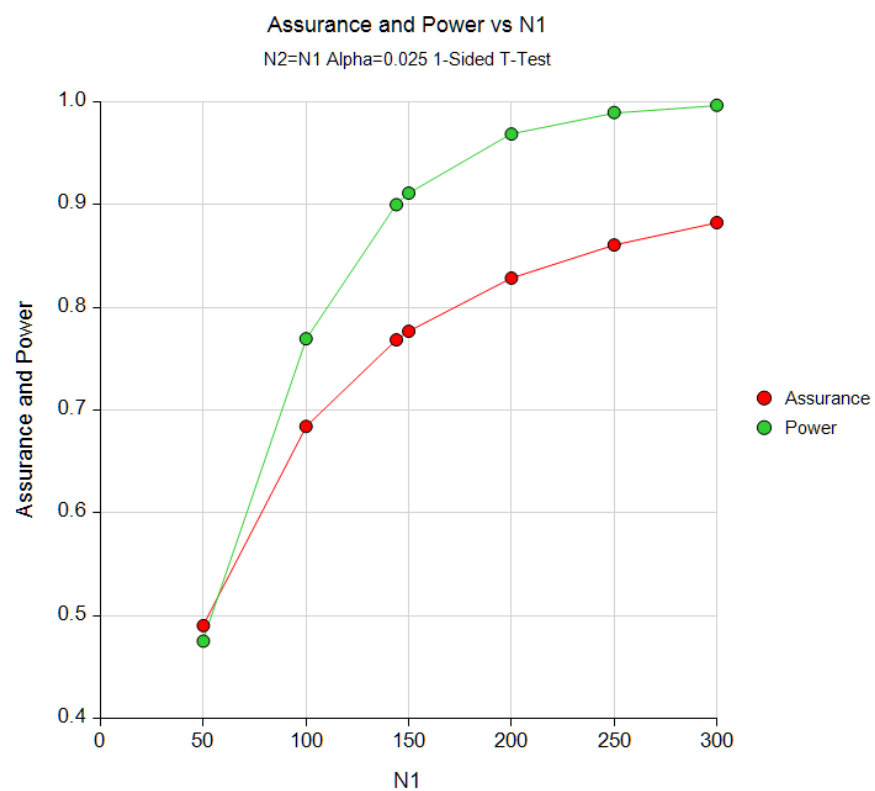
Plots



This plot shows the relationship between the assurance and sample size. Note the diminishing impact on assurance of each increase in the number of subjects.

Comparison Plots Section

Comparison Plots



This plot shows the relationship of assurance, power, and sample size.

Example 2 – Validation using Hand Computation

We could not find a validation example in the literature, so we have developed a validation example of our own. Suppose a non-inferiority, two-sample t-test will be used in which $N1 = N2 = 70$ and the significance level is 0.025. The non-inferiority margin was set to 1.0. Higher means are better.

The prior distribution of the difference will be approximated by the following table.

δ	Prob
5	0.3
6	0.4
7	0.3

The prior distribution of the standard deviation will be approximated by the following table.

σ	Prob
12	0.2
16	0.6
20	0.2

Note that in both of these tables, the parameter values are equi-spaced. This is important when using a discrete approximation such as we have here.

The *Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance* procedure is used to compute the power for each of the nine combinations of δ and σ . The results of these calculations were as follows.

Numeric Results

Solve For: Power
 Test Type: Two-Sample Equal-Variance T-Test
 Difference: $\delta = \mu_1 - \mu_2 = \mu_T - \mu_R$
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$

Power	Sample Size			Non-Inferiority Margin -NIM	Mean Difference δ	Standard Deviation σ	Alpha
	N1	N2	N				
0.83582	70	70	140	-1	5	12	0.025
0.59604	70	70	140	-1	5	16	0.025
0.42172	70	70	140	-1	5	20	0.025
0.92881	70	70	140	-1	6	12	0.025
0.72916	70	70	140	-1	6	16	0.025
0.53834	70	70	140	-1	6	20	0.025
0.97480	70	70	140	-1	7	12	0.025
0.83582	70	70	140	-1	7	16	0.025
0.65172	70	70	140	-1	7	20	0.025

The assurance calculation is made by summing the quantities $\left[(power_{i,j})(p(\delta_i))(p(\sigma_j)) \right]$ as follows

$$Assurance = (0.83582 \times 0.3 \times 0.2) + (0.59604 \times 0.3 \times 0.6) + \dots + (0.65172 \times 0.3 \times 0.2) = 0.72315.$$

Assurance for Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance

To run this example, the spreadsheet will need to be loaded with the following four columns in which the first two are for the difference, δ , and the second two are for the standard deviation, σ .

C1	C2	C3	C4
5	0.3	12	0.2
6	0.4	16	0.6
7	0.3	20	0.2

Setup

If the procedure window is not already open, use the PASS Home window to open it. The parameters for this example are listed below and are stored in the **Example 2** settings file. To load these settings to the procedure window, click **Open Example Settings File** in the Help Center or File menu.

Design Tab

Solve For	Assurance
Prior Entry Method	Individual (Enter a prior distribution for each applicable parameter)
Higher Means Are	Better (H1: $\delta > -NIM$)
Alpha	0.025
Group Allocation	Equal (N1 = N2)
Sample Size Per Group	70
NIM (Non-Inferiority Margin)	1
Prior Distribution of δ	Custom (Values and Probabilities in Spreadsheet)
Column of Values	C1
Column of Pr(Values)	C2
Prior Distribution of σ	Custom (Values and Probabilities in Spreadsheet)
Column of Values	C3
Column of Pr(Values)	C4

Options Tab

Number of Computation Points for each	50
Prior Distribution	
Maximum N1 in Sample Size Search	5000

Input Spreadsheet Data

Row	C1	C2	C3	C4
1	5	0.3	12	0.2
2	6	0.4	16	0.6
3	7	0.3	20	0.2

Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Results

Solve For: [Assurance](#)
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$
 Prior Type: Independent Univariate Distributions

Prior Distributions

δ : Point List (Values = C1, Probs = C2).
 C1: 5 6 7
 C2: 0.3 0.4 0.3
 σ : Point List (Values = C3, Probs = C4).
 C3: 12 16 20
 C4: 0.2 0.6 0.2

Assurance	Power‡	Sample Size			Non-Inferiority Margin -NIM	Expected Mean Difference $E(\delta)$	Expected Standard Deviation $E(\sigma)$	Alpha
		N1	N2	N				
0.72315	0.72916	70	70	140	-1	6	16	0.025

‡ Power was calculated using $\delta = E(\delta) = 6$ and $\sigma = E(\sigma) = 16$.

PASS has also calculated the assurance as 0.72315 which validates the procedure.

Example 3 – Finding the Sample Size Needed to Achieve a Specified Assurance

Continuing with Example 1, the researchers want to investigate the sample sizes necessary to achieve assurances of 0.4, 0.5, 0.6, 0.7, and 0.8.

In order to reduce the runtime during this exploratory phase of the analysis, the number of points in the prior computation is reduced to 20. This slightly reduces the accuracy, but greatly reduces the runtime.

Setup

If the procedure window is not already open, use the PASS Home window to open it. The parameters for this example are listed below and are stored in the **Example 3** settings file. To load these settings to the procedure window, click **Open Example Settings File** in the Help Center or File menu.

Design Tab

Solve For	Sample Size
Prior Entry Method	Individual (Enter a prior distribution for each applicable parameter)
Higher Means Are	Better (H1: $\delta > -NIM$)
Assurance	0.4 0.5 0.6 0.7 0.8
Alpha	0.025
Group Allocation	Equal (N1 = N2)
NIM (Non-Inferiority Margin)	1.15
Prior Distribution of δ	Normal (Mean, SD)
Mean	0
SD	0.5
Truncation Boundaries	None
Prior Distribution of σ	Normal (Mean, SD)
Mean	3
SD	0.5
Truncation Boundaries	Left
Left Boundary	0.0001

Options Tab

Number of Computation Points for each	20
Prior Distribution	
Maximum N1 in Sample Size Search	5000

Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Reports

Numeric Results

Solve For: [Sample Size](#)
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$
 Prior Type: Independent Univariate Distributions

Prior Distributions

δ : Normal (Mean = 0, SD = 0.5).
 σ : Normal (Mean = 3, SD = 0.5), Left Boundary = 0.0001.

Assurance*			Sample Size			Non-Inferiority Margin -NIM	Expected Mean Difference $E(\delta)$	Expected Standard Deviation $E(\sigma)$	Alpha
Actual	Target	Power‡	N1	N2	N				
0.40529	0.4	0.36950	37	37	74	-1.15	0	3	0.025
0.50167	0.5	0.49052	52	52	104	-1.15	0	3	0.025
0.60317	0.6	0.63923	74	74	148	-1.15	0	3	0.025
0.70109	0.7	0.79706	107	107	214	-1.15	0	3	0.025
0.80071	0.8	0.94111	170	170	340	-1.15	0	3	0.025

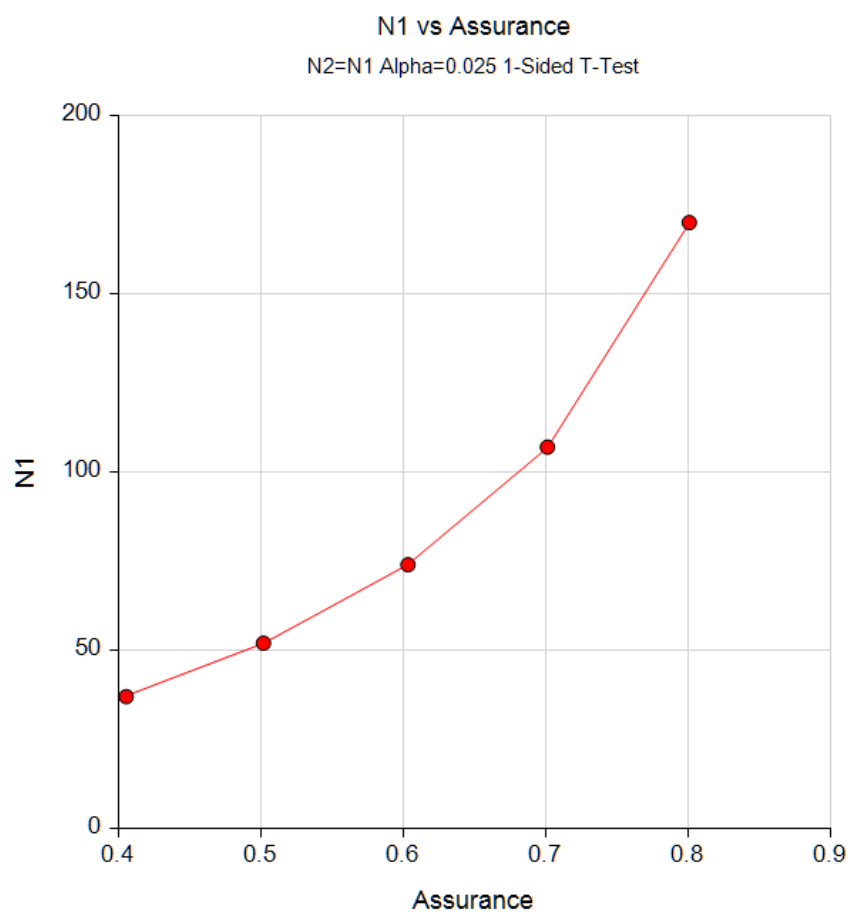
* The number of points used for computation of the prior(s) was 20.

‡ Power was calculated using $\delta = E(\delta) = 0$ and $\sigma = E(\sigma) = 3$.

This report shows the required sample size for each assurance target.

Plots Section

Plots



This plot shows the relationship between the sample size and assurance.

Example 4 – Joint Prior Distribution

Suppose a non-inferiority, two-sample t-test will be used in which $N1 = N2 = 70$ and the significance level is 0.025. The non-inferiority margin was set to 1.0. Higher means are better.

The joint prior distribution of the difference and standard deviation is approximated by the following table. Note the relationship between the difference and the standard deviation.

δ	σ	Prob
4	11	0.1
5	12	0.2
6	13	0.1
6	15	0.3
7	16	0.4
8	17	0.3
11	19	0.1
13	20	0.2
15	21	0.1

To run this example, the spreadsheet will need to be loaded with the following three columns.

C1	C2	C3
4	11	0.1
5	12	0.2
6	13	0.1
6	15	0.3
7	16	0.4
8	17	0.3
11	19	0.1
13	20	0.2
15	21	0.1

Setup

If the procedure window is not already open, use the PASS Home window to open it. The parameters for this example are listed below and are stored in the **Example 4** settings file. To load these settings to the procedure window, click **Open Example Settings File** in the Help Center or File menu.

Design Tab

Solve For	Assurance
Prior Entry Method	Combined (Enter parameter values and probabilities on spreadsheet)
Higher Means Are	Better (H1: $\delta > -NIM$)
Alpha	0.025
Group Allocation	Equal ($N1 = N2$)
Sample Size Per Group	70
NIM (Non-Inferiority Margin)	1

Assurance for Two-Sample T-Tests for Non-Inferiority Assuming Equal Variance

Column of δ Values **C1**
 Column of σ Values **C2**
 Column of Probabilities **C3**

Options Tab

Number of Computation Points for each **50**
 Prior Distribution
 Maximum N1 in Sample Size Search **5000**

Input Spreadsheet Data

Row	C1	C2	C3
1	4	11	0.1
2	5	12	0.2
3	6	13	0.1
4	6	15	0.3
5	7	16	0.4
6	8	17	0.3
7	11	19	0.1
8	13	20	0.2
9	15	21	0.1

Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Results

Solve For: [Assurance](#)
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$
 Prior Type: Joint Multivariate Distribution

Prior Distribution

Point Lists

δ : C1: 4 5 6 6 7 8 11 13 15
 σ : C2: 11 12 13 15 16 17 19 20 21
 Prob: C3: 0.1 0.2 0.1 0.3 0.4 0.3 0.1 0.2 0.1

Assurance	Power‡	Sample Size			Non-Inferiority Margin -NIM	Expected Mean Difference $E(\delta)$	Expected Standard Deviation $E(\sigma)$	Alpha
		N1	N2	N				
0.86432	0.90385	70	70	140	-1	7.88889	16	0.025

‡ Power was calculated using $\delta = E(\delta) = 7.88889$ and $\sigma = E(\sigma) = 16$.

PASS has calculated the assurance as 0.86432.

Example 5 – Joint Prior Distribution Validation

The problem given in Example 2 will be used to validate the joint prior distribution method. This will be done by running the independent-prior scenario used in that example through the joint-prior method and checking that the assurance values match.

In Example 2, the prior distribution of the difference is given as follows.

<u>δ</u>	<u>Prob</u>
5	0.3
7	0.4
9	0.3

Similarly, the prior distribution of the standard deviation is given as follows.

<u>σ</u>	<u>Prob</u>
12	0.2
16	0.6
20	0.2

The joint prior distribution can be found by multiplying the independent probabilities. This results in the following discrete probability distribution.

<u>δ</u>	<u>σ</u>	<u>P(δ)</u>	<u>P(σ)</u>	<u>P(δ)P(σ)</u>
5	12	0.3	0.2	0.06
5	16	0.3	0.6	0.18
5	20	0.3	0.2	0.06
7	12	0.4	0.2	0.08
7	16	0.4	0.6	0.24
7	20	0.4	0.2	0.08
9	12	0.3	0.2	0.06
9	16	0.3	0.6	0.18
9	20	0.3	0.2	0.06

To run this example, the spreadsheet is loaded with the following three columns. (Note that columns C3 and C4 are used to hold intermediate values which are not referenced in this example. C3 holds P(δ) and C4 holds P(σ).)

<u>C1</u>	<u>C2</u>	<u>C5</u>
5	12	0.06
5	16	0.18
5	20	0.06
7	12	0.08
7	16	0.24
7	20	0.08
9	12	0.06
9	16	0.18
9	20	0.06

Setup

If the procedure window is not already open, use the PASS Home window to open it. The parameters for this example are listed below and are stored in the **Example 5** settings file. To load these settings to the procedure window, click **Open Example Settings File** in the Help Center or File menu.

Design Tab

Solve For **Assurance**
 Prior Entry Method **Combined (Enter parameter values and probabilities on spreadsheet)**
 Higher Means Are **Better (H1: $\delta > -\text{NIM}$)**
 Alpha **0.025**
 Group Allocation **Equal (N1 = N2)**
 Sample Size Per Group **70**
 NIM (Non-Inferiority Margin) **1**
 Column of δ Values **C1**
 Column of σ Values **C2**
 Column of Probabilities **C5**

Options Tab

Number of Computation Points for each **50**
 Prior Distribution
 Maximum N1 in Sample Size Search **5000**

Input Spreadsheet Data

Row	C1	C2	C3	C4	C5
1	5	12	0.3	0.2	0.06
2	5	16	0.3	0.6	0.18
3	5	20	0.3	0.2	0.06
4	6	12	0.4	0.2	0.08
5	6	16	0.4	0.6	0.24
6	6	20	0.4	0.2	0.08
7	7	12	0.3	0.2	0.06
8	7	16	0.3	0.6	0.18
9	7	20	0.3	0.2	0.06

Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Results

Solve For: [Assurance](#)
 Higher Means Are: Better
 Hypotheses: $H_0: \delta \leq -NIM$ vs. $H_1: \delta > -NIM$
 Prior Type: Joint Multivariate Distribution

Prior Distribution

Point Lists

δ : C1: 5 5 5 6 6 6 7 7 7

σ : C2: 12 16 20 12 16 20 12 16 20

Prob: C5: 0.06 0.18 0.06 0.08 0.24 0.08 0.06 0.18 0.06

Assurance	Power‡	Sample Size			Non-Inferiority Margin -NIM	Expected Mean Difference $E(\delta)$	Expected Standard Deviation $E(\sigma)$	Alpha
		N1	N2	N				
0.72315	0.72916	70	70	140	-1	6	16	0.025

‡ Power was calculated using $\delta = E(\delta) = 6$ and $\sigma = E(\sigma) = 16$.

PASS has calculated the assurance as 0.72315 which matches the result in Example 2. This validates the joint prior method.