

# Understanding ANOVA: Conducting One-Way Analysis with Unequal Sample Sizes

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## RECOMMENDED CITATION

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In the field of [statistics](#), a frequent inquiry from students and researchers concerns the fundamental requirements for the [Analysis of Variance \(ANOVA\)](#). Specifically, many question the necessity of balancing experimental groups:

### **Is it permissible to perform a one-way ANOVA when the sample sizes of the groups being compared are unequal?**

The definitive short answer is **Yes**. You can absolutely perform a [one-way ANOVA](#) even when the group sample sizes ( $n$ ) are not equivalent. The assumption of equal sample sizes is generally not a mandatory prerequisite for the ANOVA model itself.

However, while statistically possible, proceeding with unequal sample sizes introduces potential methodological complications that must be rigorously addressed. Researchers should be acutely aware of two primary risks when analyzing data with unequal group sizes (an unbalanced design):

Reduced [statistical power](#).

Diminished [robustness](#) against violations of the assumption of equal variance (homoscedasticity).

The subsequent sections delve into these critical issues, providing necessary context and a structured decision-making protocol for proceeding with unbalanced designs.

### **The Primary Concern: Reduced Statistical Power**

When employing any inferential statistical test designed to compare means across different populations, the concept of [statistical power](#) is paramount. Statistical power is formally defined as the probability that a test will correctly reject the null hypothesis--that is, the probability of detecting a true effect when one genuinely exists. A study with low power risks committing a Type II error (a false negative).

It is a well-established principle in experimental design that the statistical power of a test is maximized when the sample sizes across all comparison groups are perfectly equal. This configuration provides the most efficient use of resources and yields the narrowest confidence intervals, optimizing the probability of detecting subtle differences between means.

Conversely, mathematical proofs demonstrate that as the disparity in sample sizes between groups increases, the overall statistical power of the ANOVA decreases. An unbalanced design means that the study is less likely to detect an existing difference. This reduction in power is the central reason why researchers typically aim for equivalent sample sizes whenever feasible, ensuring the greatest probability of identifying scientifically meaningful effects.

## Impact on Robustness: Heteroscedasticity and Unequal N

A cornerstone assumption of the standard one-way ANOVA model is the [homogeneity of variances](#) (also known as homoscedasticity), which stipulates that the population variances of the dependent variable must be equal across all groups. Statistical tests, including the ANOVA, are often described as having [robustness](#) against minor violations of their underlying assumptions.

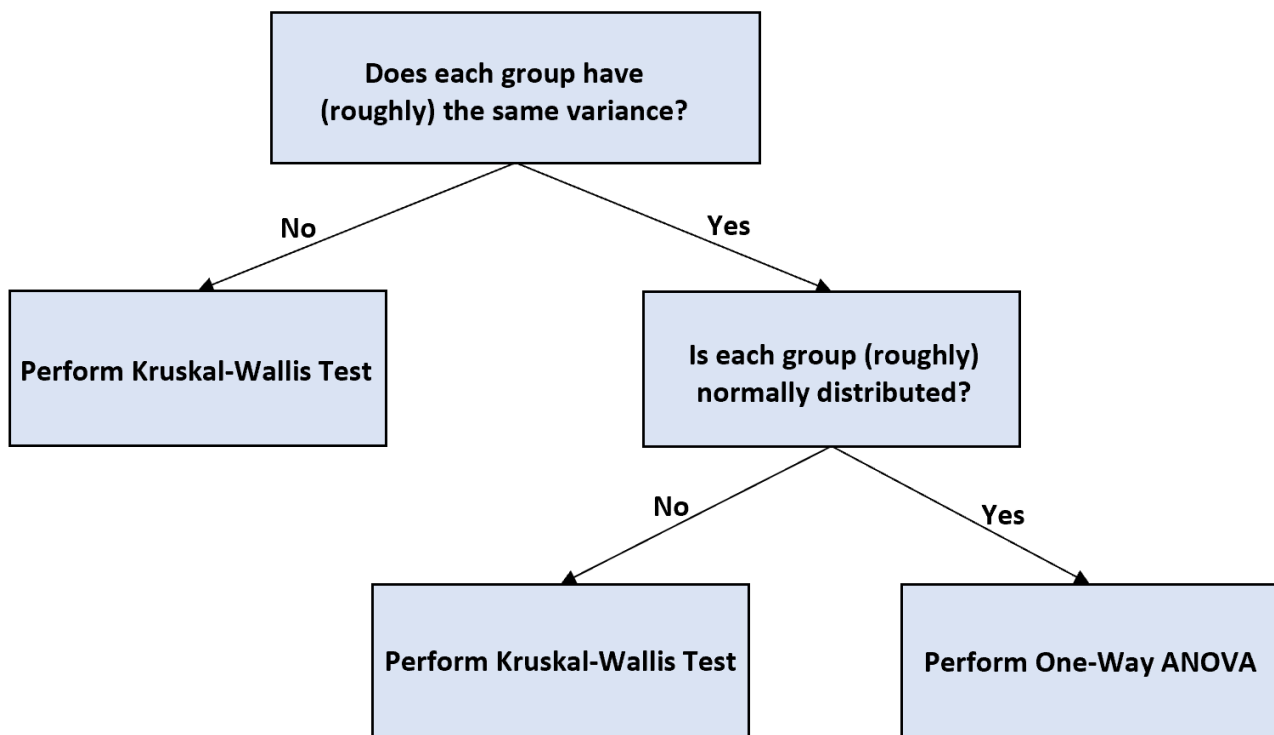
The standard one-way ANOVA is generally robust against moderate violations of the equal variances assumption, provided one critical condition is met: **the sample sizes of the groups must be equal**. When  $n$  is equal, the test is highly forgiving of minor variance differences.

When the variances are unequal (a condition called heteroscedasticity) AND the sample sizes are also unequal, the ANOVA becomes highly compromised. In these specific circumstances, the F-statistic can be severely biased, leading to unreliable p-values. If the larger variances are associated with the smaller sample sizes, the test tends to become overly conservative (reducing power further). Conversely, if the larger variances are associated with the larger sample sizes, the test becomes overly liberal (inflating the Type I error rate).

## Decision Protocol for Handling Unbalanced Designs

Given the risks associated with reduced power and diminished robustness when both variances and sample sizes are unequal, researchers must follow a systematic protocol before interpreting the results of a one-way ANOVA with unbalanced data. The decision of whether to proceed with the standard ANOVA or utilize an alternative non-parametric test hinges entirely upon the fulfillment of two critical assumptions: the equality of variances and the [normality](#) of the data distribution.

If you have unequal sample sizes and wish to perform a one-way ANOVA to test for differences between group means, you can use the following flow chart to decide how to proceed:



This systematic approach ensures that the chosen test remains statistically valid despite the asymmetry in the sample sizes.

## Step-by-Step Guide to Assumption Checks

To implement the decision protocol outlined above, two primary checks are necessary to assess the distribution and spread of the data within each group:

### Checking for Homogeneity of Variances (Step 1)

The first critical step involves determining whether the population variances are homogeneous across all groups. If significant differences exist in variance, the standard ANOVA should generally be avoided when sample sizes are unequal.

Researchers can employ one of two methods to assess variance equality:

**Visual Assessment:** Create boxplots for each group and visually inspect the spread (or height) of the boxes. If the spread of values in each group is roughly comparable, the assumption may be tentatively met.

**Formal Statistical Test:** Conduct a formal hypothesis test specifically designed to check for equal

variances, such as [Levene's Test](#). A non-significant result from these tests suggests that the variances are statistically equal.

If the variances are found to be unequal (heteroscedasticity) when sample sizes are unequal, it is often best to perform the Welch's ANOVA, which is designed to handle this scenario. If the variances are determined to be equal, the analysis proceeds to the second major assumption check.

### Checking for Normality (Step 2)

The second major assumption check determines whether the data within each group are [normally distributed](#). While ANOVA is relatively robust to non-normality, especially with larger sample sizes, this check is crucial when dealing with unbalanced data that passed the variance check.

Methods for assessing normality include:

**Visual Assessment:** Generate histograms or Q-Q plots for the data in each group. A close approximation to a bell curve in the histogram or points lying close to the diagonal line on the Q-Q plot suggests normal distribution.

**Formal Statistical Tests:** Utilize established tests such as Shapiro-Wilk, Kolmogorov-Smirnov, Jarque-Barre, or D'Agostino-Pearson. A non-significant result indicates that the data are likely drawn from a normally distributed population.

If all groups demonstrate a roughly normal distribution, you can confidently proceed to perform a standard one-way ANOVA and interpret the results in the usual manner. If, however, the normality assumption is violated, the recommended non-parametric alternative is the [Kruskal-Wallis Test](#), which compares median ranks rather than means.

### Alternative Approaches for Handling Unbalanced Data

When the decision protocol confirms that the standard one-way ANOVA is inappropriate due to severe violations of assumptions combined with unequal sample sizes, researchers have robust alternatives available.

If the variances are unequal, researchers should prioritize the **Welch's ANOVA**. This test is a modified version of the ANOVA that adjusts the degrees of freedom to account for unequal variances. It is superior to the traditional F-test when homoscedasticity is violated.

If the normality assumption is violated, regardless of variance equality, the [Kruskal-Wallis Test](#) should be used. This test is considered the non-parametric equivalent to a one-way ANOVA and is highly suitable for data derived from non-normal distributions or ordinal data.

Choosing the correct statistical technique based on rigorous assumption checks is essential for maintaining the integrity and validity of your research findings, especially when navigating the complexities presented by unequal sample sizes in experimental design.