participant does not have the same opportunity to gain. A participant who scores very low on a pretest has a large opportunity to gain, but a participant who scores very high has only a small opportunity to improve (referred to as the *ceiling effect*). Who has improved, or gained, more—a participant who goes from 20 to 70 (a gain of 50) or a participant who goes from 85 to 100 (a gain of only 15 but perhaps a perfect score)? Second, gain or difference scores are less reliable than analysis of posttest scores alone.

The appropriate analysis for two pretest-posttest groups depends on the performance of the two groups on the pretest. For example, if both groups are essentially the same on the pretest, neither group has been previously exposed to its treatment, then posttest scores are best compared using a t test. If, on the other hand, there is a difference between the groups on the pretest, the preferred approach is the analysis of covariance. Recall that analysis of covariance adjusts posttest scores for initial differences on some variable (in this case the pretest) related to performance on the dependent variable. To determine whether analysis of covariance is necessary, calculate a t test on the two pretest means. If there is a significant difference between the two pretest means, use the analysis of covariance. If not, a simple t test can be computed on the posttest means.

Simple Analysis of Variance

Simple, or *one-way,* **analysis of variance (ANOVA)** is used to determine whether there is a significant difference between two or more means at a selected probability level. Thus, for a study involving three groups, ANOVA is the appropriate analysis technique. Like two posttest means in the t test, three (or more) posttest means in ANOVA are very unlikely to be identical, so the key question is whether the differences among the means represent true, significant differences or chance differences due to sampling error. To answer this question ANOVA is used and an **F ratio** is computed. You may be wondering why you cannot just compute a bunch of t tests, one for each pair of means. Aside from some statistical problems concerning distortion of your probability level, it is more convenient to perform one ANOVA than several t tests. For example, to analyze four means, six separate t tests would be required ($\overline{X}_1 - \overline{X}_2, \overline{X}_1 - \overline{X}_3, \overline{X}_1 - \overline{X}_4, \overline{X}_2 - \overline{X}_3, \overline{X}_2 - \overline{X}_4, \overline{X}_4 - \overline{X}_3$). ANOVA is much more efficient and keeps the error rate under control.

The concept underlying ANOVA is that the total variation, or variance, of scores can be divided into two sources—variance between groups (variance caused by the treatment groups) and variance within groups (error variance). A ratio is formed, with group differences as the numerator (variance between groups) and error in the denominator (variance within groups). It is assumed that randomly formed groups of participants are chosen and are essentially the same at the beginning of a study on a measure of the dependent variable. At the end of the study, the researcher determines whether the between groups (or treatment) variance differs from the within groups (or error) variance by more than what would be expected by chance. In other words, if the treatment variance is sufficiently larger than the error variance, a significant F ratio results; the null hypothesis is rejected and it is concluded that the treatment had a significant effect on the dependent variable. If, on the other hand, the treatment variance and error variance do not differ by more than what would be expected by chance, the resulting F ratio is not significant and the null hypothesis is not rejected. The greater the difference, the larger the F ratio. To determine whether the F ratio is significant, an F table is entered at the place corresponding to the selected probability level and the appropriate degrees of freedom. The degrees of freedom for the F ratio are a function of the number of groups and the number of participants.

Calculating Simple Analysis of Variance (ANOVA)

Suppose we have the following set of posttest scores for three randomly selected groups.