CONTENT OVERVIEW

In an **observational study** we observe subjects and measure the variables of interest, explanatory variables and responses. For example, in studying the effects that humans have on the coral reefs, we go to several locations where the level of human habitation varies and then observe the conditions of the coral reefs in those areas. Even though we might observe that coral reefs are less healthy if near highly populated areas than near uninhabited areas, we can't say that humans are *causing* the damage observed. Observational studies allow us to observe association between an explanatory variable and a response variable, but we cannot use the observational study to establish a cause-and-effect relationship between the explanatory variable and response variable. In order to establish a cause-and-effect relationship, we need to conduct an **experiment**.

In an experiment, the researcher imposes some **treatment** on the subjects and then observes their responses. In the case of coral reefs, that would mean that we find some uninhabited areas with coral reefs, and then bring people in to live around one or more of those areas, and finally, after a period of time, we compare what happens to the coral reefs. If we observed damage associated with inhabited areas, then we could say that the **factor**, the explanatory variable human habitation, caused the damage to the coral reefs.

The basic ideas of experimental design are among the most important in statistics, and perhaps the most influential. Methods of conducting research in many of the applied sciences, from agricultural research to medicine, have been revolutionized by the use of statistically designed experiments. The distinction between observation and experiment is important. For example, measuring the height, weight, and blood pressure of a doctor's patients during their office visits and similar data-collection procedures are considered observation. While it may be true that observing, say, a patient's weight, may disturb the patient and so change their response (maybe they lose weight before the next visit and their blood pressure goes down), it is not an experiment. Experiments deliberately impose some treatment on the subjects in order to see how they respond.

In the science classroom, many experiments do not have the **randomized, comparative design** that was stressed in the video. Instead, in the controlled environment of a laboratory, many experiments have a simpler design:

Treatment ➞ Observe outcome

For example,

> Mix chemicals → Observe explosion

However, for agricultural or ecological experiments in the field or in experiments involving living subjects that vary a lot, this simple design invites **confounding** – mixing of a variety of causes, even those not considered in the experiment. Uncontrolled medical experiments, for example, have led doctors to conclude that worthless treatments worked. The natural optimism of the doctors who had invented the treatment, the **placebo effect** (the strong effect on patients of any treatment given even if the treatment is fake), and perhaps an unrepresentative group of patients combined to make the worthless treatments look good. Later, randomized comparative experiments found that the treatments had no value. Doctors gradually recognized that well-designed experiments were essential.

Agricultural researchers learned this earlier. Variation in the weather alone is enough to force experiments with new crop varieties to be comparative. The yield of a new variety this year may look great, but this was a good growing season. The virtues of the new variety are confounded with the effects of weather unless we do a comparative experiment in which older varieties were also grown. Unpredictable variation in soil makes random assignment of competing crop varieties to small growing plots desirable. In fact, statistical design of experiments first arose in the 1920s to solve the problems encountered by agricultural field trials.

Principles of experimental design

The basic principles of statistical design of experiments are:

1. **Randomization:** Use of impersonal chance to assign subjects to treatments to remove bias and other sources of extraneous variation. Randomization produces groups of subjects that should be similar in all respects before the treatments are applied. It allows us to equalize across all treatments the effects from unknown or uncontrollable sources of variation.

2. **Replication:** Repeat the experiment on many subjects to reduce chance variation in the results.

3. **Local Control:** Control all factors except the ones under investigation. Some examples of local control include: assigning equal numbers of subjects to each treatment, applying treatments uniformly and under standardized conditions, sorting subjects into homogeneous groups, and comparing two or more treatments.

In a **randomized comparative design** subjects are randomly assigned to treatment groups in order to study the effect the treatment has on the response. Figure 15.1 is an outline of the basic design for comparing two treatments.
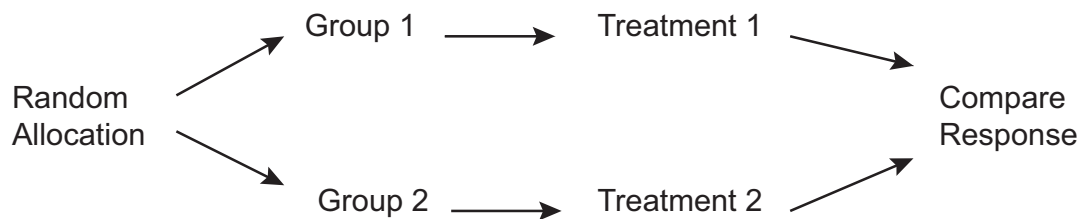

Figure 15.1. Outline of basic design for comparing two treatments.

Use this pictorial description rather than attempting a full description in words of an experimental design. Make the general design specific by adding the size of the groups, substituting the actual treatments compared (in place of Treatment #) and the response recorded. Notice that "treatment" is used for whatever is imposed on the subjects in an experiment, not only medical treatments.

The logic behind a randomized comparative design is straightforward. Randomization produces groups of subjects that should be similar in all respects before the treatments are applied. A comparative design ensures that influences other than the experimental treatments operate equally on all groups. Therefore, differences in the response variable must be due to the effects of the treatments – that is, the treatments are not only associated with the observed differences in the response, but must actually cause them.

To do the random assignment of subjects to groups, use a table of random digits or a random number generator (which is built into graphing calculators, as well as into spreadsheet and statistical software).

Randomizing treatments using a table of random digits

You can find a table of random digits in most introductory statistics textbooks as well as on the Internet. A random digits table has the following properties:

- Each entry in the table is equally likely to be any of the 10 digits
  0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

- The entries are independent of each other. That is, knowledge of one part of the table gives no information about any other part.

A random digits table is one long string of random digits. The numbers are generally arranged in groups of five and the rows numbered for convenience. Two digits from the table are equally likely to be any of the 100 possibilities 00 to 99, and so on. To choose at random, assign the subjects numerical labels and let the table choose from these labels at random.

For example, to choose at random 10 out of 20 subjects to get Treatment 1 (aspirin), label the subjects 01 to 20 and enter the random digits table on any line (vary the entry point each time you use the table), say line 110, which is given below.

> 38448 48789 18338 24697 39364 42006 76688 08708

Read two-digit groups because we assigned two-digit labels. Just skip over all groups not used as labels. So, skip 38, 44, 84, 87, and 89. The first subject chosen has label number 18. Continue this process until 10 subjects are chosen – next select 20, 06, 08, and so forth. Assign the 10 selected subjects to the aspirin treatment. The remaining subjects get the placebo.

Randomizing treatments using a random number generator

Graphing calculators and spreadsheet and statistical computing software have random number generators. Rand (TI graphing calculators and Excel) generates a number from the uniform distribution on the interval from 0 to 1. Suppose you have a list of 10 subjects and you want to choose five of them to assign to Treatment 1 (aspirin).

Step 1: Use a random number generator to assign a random number to each person. Excel's Rand() was used to generate the set of random numbers in Table 15.1.

Subjects	Rand
Joe	0.305127
Sally	0.130861
Kelly	0.335956
Bruce	0.525466
Marsha	0.288252
Caitlin	0.036762
George	0.084562
Jian	0.763097
Cheryl	0.753380
Ying	0.775420

Table 15.1. Assigning a random number to subjects.

Step 2. Sort the names so that the first name is the name associated with the smallest random number and the last name is associated with the largest random number. Table 15.2 shows the results.

Subjects	Rand
Caitlin	0.036762
George	0.084562
Sally	0.130861
Marsha	0.288252
Joe	0.305127
Kelly	0.335956
Bruce	0.525466
Cheryl	0.753380
Jian	0.763097
Ying	0.775420

Table 15.2. Names sorted by random number.

Step 3. Select the first five names from the sorted list to assign to the aspirin treatment.

So, in this case, Caitlin, George, Sally, Marsha, and Joe would be assigned to the aspirin treatment and the remaining subjects would be assigned to the placebo group.

Who knows who is getting which treatment?

Particularly in the context of medical studies, it is important to know whether or not the participants know which treatment they are getting and whether or not those recording the responses know. In **double-blind experiments** neither the participants nor those conducting the experiment know which participants were assigned to which treatments. In a **single-blind** experiment the participants do not know which treatment they are receiving but those conducting the experiment do know.