Introduction to Experimental Design

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Introduction to Statistical Data Analysis (ADSC1000)

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Topics

Introduction

- We have already spoken about some sampling methods, now we will talk about designing our own experiments.
- We use experiments to understand and improve many systems.
  - Material & Biological sciences
  - Industrial production
  - Agriculture
  - Clinical trials for medicine
  - Different managerial structures
  - Product focus groups
- It is important to be able to draw statistically sound inferences.

Why Design?

- Example: A study of 1430 women were asked whether they smoked. Ten years later, a follow-up survey observed whether each woman was still alive or deceased.
- Results:
  - 21% of the smokers died
  - 32% of the nonsmokers died
- Smoking makes you live longer?
- **No, we are missing important *lurking* variables in the experiment.**
  - Diet
  - Age
  - Activity levels
  - Pre-existing medical conditions

Observational Studies & Experiments

- In an **observational study**, data is observed in its natural environment.
  - It *cannot* be proven that the relationships detected are cause and effect.
- In an **experiment** the environment is controlled. Some variables are purposely changed while others are held constant.

Experiment Design

- Experiments are designed in ways to improve the overall experiment.
- An **experiment** deliberately imposes some treatment on individuals in order to observe their responses.
- Early agricultural experimental designs began in the 1930s.

Definitions for Design

- The experimental conditions to be applied and evaluated are called **treatments**.
- The unit (group) to which the treatment is applied is called the **experimental unit**.
- When the experimental unit is a person the units are called **subjects**.
- **Trial (or run)**: application of a treatment to an experimental unit.

Experiments

- Divide the experimental units into a number of different groups corresponding to the number of treatments to be tested.
- Apply different treatments to each group.
- Measure the units to see if there are differences between the treatments.

Definitions for Experiments

- The **Dependent Variable/Response Variable** is the characteristic of the *experimental unit* that is measured after each experiment or run.
- **Factors** combine to form treatments. Factors are variables whose influence on the response variable is examined.
- **Levels** represent the individual settings for each factor.
- In other words, factors are the explanatory variables for the response variable and the levels represent the possible values of the factors.

Example 1

- An experiment was carried out on 18 patients to determine the effect of gold alloys and the sintering process on the hardness (measured by Diamond Pyramid Hardness) of dental fillings.
- Two gold alloys were used: Au 97-1-1-1 and AuCa.
- Fillings were sintered (fused and hardened) at three different temperatures: 1500° F, 1600° F, and 1700° F.
- Identify the experimental units (subjects), factors (treatments), levels, response variable, and how to design the experiment.

Example 1 Solutions

- Experimental units (subjects):
- Factors (treatments):
- Levels:
- Response variable:
- Design:

Example 2

- An experiment was carried out on 32 strips of plastic film to determine the effect of film thickness as well as temperature and length of the film wash on the resulting luster (shine) of the film.
- One of two thicknesses of film were used (1 and 2 millimeters).
- The film was washed for 20, 30, 40 or 60 minutes
- The film was dried at either 92º C or 100º C
- Identify the experimental units (subjects), factors (treatments), levels, response variable, and how to design the experiment.

Example 2 Solutions

- Experimental units (subjects):
- Factors (treatments):
- Levels:
- Response variable:
- Design:

Principles of Experimental Design

- Replication
- Randomization
- Blocking

Replication

- Repeat the experiment under the same conditions.
- Apply each treatment to units that are representative of the population.
- Reduces the standard error leading to more credible results.

Randomization

- Use of a chance mechanism to assign treatments to units or to run order.
- Protects against latent variables or "lurking" variables (Example: number of volunteers).
- Reduces the potential influence of of subjective bias in treatment assignments (Example: clinical trials).
- Ensure validity of statistical inference.

Blocking

- A **block** refers to a collection of homogeneous units.
  - Examples: production batches, geographical locations, and similar people.
- Effective blocking means that there is a larger between-block variation than within-block.
- Treatments can then be ran and compared within the same blocks.
- Using randomization within blocks can eliminate block-block variation and reduce variability of treatment effects estimates.

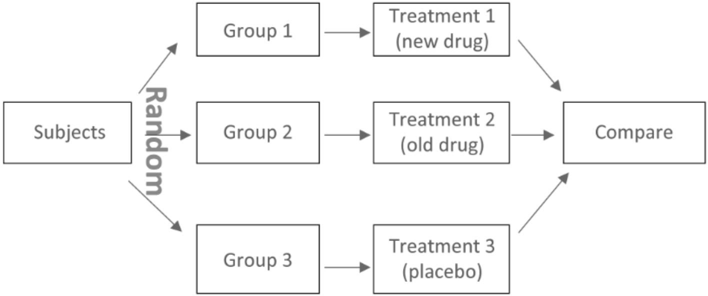
Logic of Experimental Design

- Randomization of subjects yields groups that are similar in all respects before the treatments are applied.
- Comparative design ensures that influences other than the treatments operate equally on all groups
- Resulting in:
  - Differences in the average response to the treatments is due either to the treatments or to outcome of the randomization.
  - Evidence suggests that the treatments cause the differences to occur.

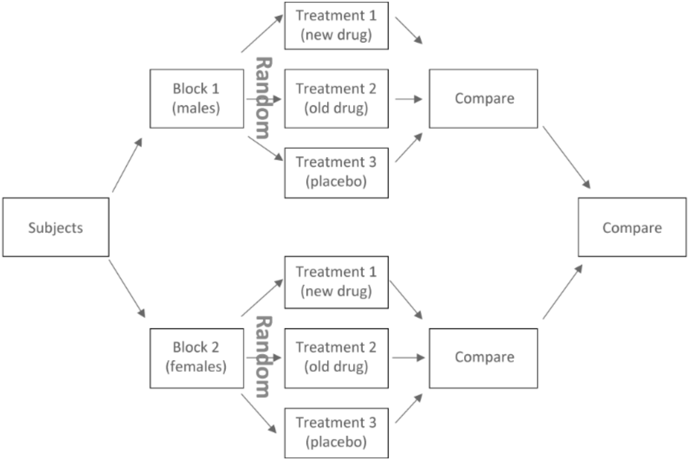
Two Types of Experimental Designs

- **Completely randomized design**
  - All experimental units are allocated at random among all the treatments
- **Randomized block designs**
  - Experimental units are divided into groups of similar units called blocks.
  - Within the block the experimental units are allocated at random among all the treatments.

Completely Randomized Design



Randomized Block Design



Completely Randomized Design Example

- Plant densities and plant yields:
  - Experimental unit: plots of land.
  - Randomization: randomly divide fifteen plots into five groups of three.
  - Treatments (explanatory variable): five plant densities (10, 20, 30, 40 or 50 plant stalks per square yard); assign a treatment level to each group.
  - Replication: Three plots per treatment level.
  - **Response Variable:** Plant mass yield.

Randomized Block Design Example

- Plant densities and plant yields:
  - Experimental unit: plots of land.
  - **Blocking:** The field was irrigated with a water gradient in the field–field divided into four areas (blocks) that were in the same part of the water gradient.
  - Randomization: randomly divide the plots in an area into treatment groups.
  - Treatments (explanatory variable): five plant densities (10, 20, 30, 40 or 50 plant stalks per square yard); assign a treatment level to each group.
  - **Response Variable:** Plant mass yield.

Statistical Significance

- The goal is to compare the effects of different levels of the treatments on the response.
- We implement designs to our experiments to try to minimize the possible effects of *lurking* or *confounding* factors (variables).
- We are able to draw conclusions about the impacts of the factors when an observed effect is so large (or observed effects that are so different) it would rarely occur by chance.
- We can then apply our statistical inference tools to determine if the observed differences are significant.

Exercise 1

- An experiment was carried out on 24 tomato plants to determine the effects of watering levels and fertilizer on the mass of the tomatoes.
- Two different fertilizers (Fertilizer A, & Fertilizer B) were used.
- Three different water levels were used (100ml, 200ml, 400ml per day).
- Identify the experimental units (subjects), factors (treatments), levels, response variable, and how to design the experiment.

Exercise 2

- Think of an example experiment where blocking would improve the reliability of the experiment.

References & Resources

1. Oehlert, G. W. (2010). *A first course in design and analysis of experiments.*
2. Lawson, J. (2014). *Design and Analysis of Experiments with R (Vol. 115)*. CRC press.

- Experimental Design in Statistics