INTRODUCTION

R. A. Fisher

In 1919, R. A. Fisher had been appointed statistician at Rothamsted Experiment Station at Harpenden, England. In the next few years, Fisher invented **experimental design**: Fisher elucidated “the underlying theory and provided the statistical methods that research workers urgently needed to deal with the ubiquitous variation encountered in biological experimentation.” (Box, 1997)[1]

His daughter, Joan Fisher Box, recounted the history of this period in the article: Box, JF (1980). “R. A. Fisher and the Design of Experiments, 1922-1926”.

R. A. Fisher was arguably the most important statistician of the last century. He made foundational contributions to many branches of statistics and genetics.[2]

The value or the worthlessness

At Rothamsted, Fisher was initially tasked with analyzing immense data from crop field experiments that had been collected since 1840: he mastered the analysis of variance (ANOVA) and invented the method of maximum likelihood.

Yet, according to Joan Box (1980), after a few years at Rothamsted, Fisher recognized that **“the amount of information extracted in the process of estimation could never exceed the quantity supplied by the data”** and “a statistician, so long as he had his arithmetic right, had no responsibility for the value or the worthlessness of his estimates; consequently, ‘the weight of his responsibility was thrown back on to **the processes by which the data has come into existence**’ (Fisher, 1947). Fisher accepted the design of experiments as his charge.”

Design/plan ahead or face a post-mortem examination

Later(in 1938[1]), Fisher famously said:

“To consult the statistician after an experiment is finished is often merely to ask him to conduct a post mortem examination. He can perhaps say what the experiment died of.”

Reflecting on history, the first lesson we want to learn is this: Don’t do the experiments and collect data first, and then ask what these data can tell us.

Budget time/resources for a good experimental design.

Sad stories from our consulting practicum[2]: we do a lot of “post mortem examinations”. If you have a wrong design—i.e., if your design does not match your research question—your experimental data will not answer the question you want to answer.

The Arrangement of Field Experiments

Fisher articulated the foundational principles of experimental design in the 1926 paper "The Arrangement of Field Experiments" and later in the 1935 book "Design of Experiments".

Joan Box (1980) commented on the 1926 paper: "Apart from a few pages on design in Statistical Methods for Research Workers (1925)[1], this was Fisher's first discussion of the design of experiments. In it the principles of **randomization**, **replication**, and **blocking** were enunciated, their application was exemplified using randomized Latin square and factorial block designs, and the possibilities of confounding were introduced. The aims of Fisher's experimental design were radically new: Whereas Russell's explicit aim was precision, Fisher's overriding considerations were **validity and efficiency**."

Statistical Methods for Research Workers

I'd also like to comment on the 1925 book, "Statistical Methods for Research Workers". From the title, you can see that Fisher wrote this book for research workers. Fisher was a great communicator of statistics. Fisher was probably one of the most sophisticated statistician at that time: he had already invented the method maximum likelihood. Yet he made his effort to make this book accessible to research workers who may not know that much statistics. It shows that: first, **Fisher valued science**; and second, he **understood the importance of communicating statistical ideas**. Both these factors contributed the quick acceptance of his experimental design principles by his contemporaries.

Equally importantly, the research workers at Rothamsted were also open-minded and eager to learn statistical methods!

Start with a research question

Experimental design should start with a clearly stated research question. **The science and the research question should always come before the experiment.**

We design and perform experiments to answer an interesting research question. For each aspect of the design, we have to ask ourselves does our design choice help us better understand the research question, how and why.

This should be obvious, but sometimes it is overlooked, and the experiment becomes disconnected from the research question.

In 1919, Fisher had other opportunities, but he chose to go to Rothamsted, so that he could be close to the research workers and to better understand field experiments.

Comparative experiments

In this class, we mainly focus on comparative experiments where we compare the effects of different treatments, for example:

- compare the effects of different doses of a drug on blood pressure.
- compare the effects of irrigation methods, fertilizers on crop production.
- compare the effects of different compaction methods and materials on asphalt concrete durability.

As we will see, designed experiments are widely used in agriculture, medicine, industrial engineering, psychology, and many other fields.

Planned experiments vs. observational studies

The key difference between a **designed experiment** and an **observational study** is in a designed experiment, we control how the treatments are assigned to experimental units:

- Planned/designed experiment: A test in which **an independent variable is purposefully changed** so that we may look for changes in a dependent/response variable.
- Observational studies: or "natural experiments", involve fortuitous changes, or pre-existing differences, in an independent variable.

Many of the analysis techniques we will discuss can also be used in comparative observational studies.

However, in general, we cannot draw **causal conclusions** from an observational study; we can from a well-designed experiment.

Discussion: smokers and lung cancer.

Smokers get lung cancer more frequently than do non-smokers. Does this prove that smoking causes lung cancer?

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If we only have data from observational studies that show lung cancer is associated with smoking, we do not have **statistical evidence** that smoking **causes** lung cancer: For example, we cannot eliminate the possibility that some other factors that cause lung cancer at the same time also cause people to like smoking.

Note that we are not claiming that smoking does not cause lung cancer. What we are saying is that we cannot draw that conclusion based on associations found from an observational study.

Further examples of observational studies

Can you think of more examples of observational studies (from your own areas of research)? Can you see why we cannot draw causal conclusions from those studies? What are potentially confounding factors in these studies?

Summary

- Brief history
- Start with a research question
- Design before carrying out experiment
- Designed experiments versus observational studies