

# What is a carryover effect?

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December 10, 2025

## RECOMMENDED CITATION

stats writer (2025). *What is a carryover effect?*. PSYCHOLOGICAL SCALES. Retrieved from <https://scales.arabpsychology.com/?p=107021>

The carryover effect is a pervasive phenomenon observed across various scientific disciplines, including psychology, medicine, education, and economics. Fundamentally, it describes how the influence of a prior event, intervention, or condition persists and affects subsequent conditions or measurements, even after the initial stimulus has concluded. This continuation means that a current observation or outcome is not solely determined by the immediate circumstances but is confounded by residual factors from preceding exposures.

Understanding this effect is crucial for maintaining internal validity in research, particularly in studies involving repeated measures. Whether stemming from accumulated learning, residual medication, or lingering fatigue, the carryover effect highlights the intricate dependencies between sequential steps in an experiment or a natural process. This concept provides a powerful lens through which to analyze how past experiences consistently shape present behavior and outcomes, thereby necessitating careful methodological control.

## The Definition and Context of the Carryover Effect

In empirical research, a **carryover effect** is specifically defined as the lasting influence that transfers from one experimental treatment condition to the next, thereby potentially contaminating the results of the subsequent treatment. This is distinct from random error or simple variation; it represents a systematic bias introduced by the sequence of experimental exposures.

This phenomenon is most frequently encountered and creates the greatest methodological challenge in within-subjects research designs. In such designs, the core characteristic is that the identical group of participants is systematically exposed to every single level or condition of the independent variable. This repeated exposure, while efficient for minimizing subject variability, inherently opens the door for previous experiences--be they learning, fatigue, sensitization, or adaptation--to persist and interfere with later performance metrics. The measured response under treatment B might not be a pure measure of treatment B's efficacy, but rather a hybrid outcome reflecting B combined with the residual influence of A.

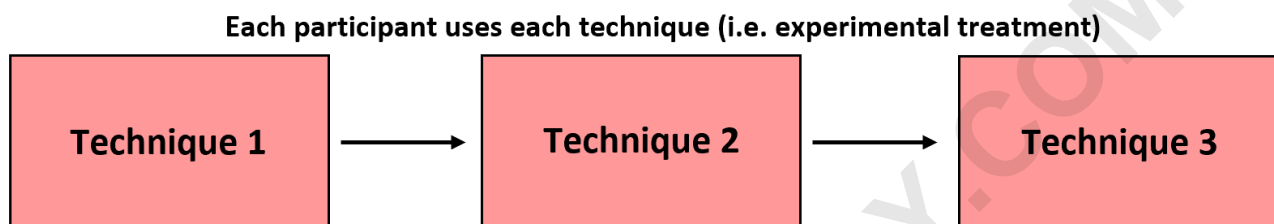
## Illustrative Example: Memory Techniques Study

Consider a hypothetical cognitive experiment designed to evaluate the effectiveness of three different mnemonic techniques (Technique 1, Technique 2, and Technique 3) aimed at improving the ability of subjects to memorize a sequence of cards in a standard deck. If we employ a within-subjects design, every participant must sequentially utilize Technique 1, Technique 2, and Technique 3.

As the experiment progresses, participants inevitably become more familiar with the core task--the card memorization itself. This accumulated skill, gained during the application of Technique 1 and

Technique 2, acts as a powerful residual factor. By the time a participant attempts Technique 3, their overall ability to memorize cards has likely increased significantly simply due to sheer practice, rather than the intrinsic superiority of Technique 3. This enhanced skill level "carries over" and artificially inflates the performance metrics observed under the later conditions.

## The Carryover Effect



*Is the participant improving because of practice or because of technique?*

### The Critical Problem of Confounding Variables

The primary reason the carryover effect presents a profound challenge to experimental rigor is its capacity to introduce confounding variables that obscure the true relationship between the independent and dependent variables. When performance differences are observed between treatment groups, the researcher is left with an ambiguous interpretation: Is Technique 3 genuinely superior to Technique 1, or did the participant perform better simply because they had substantial time to warm up, practice, and refine their task approach during the preceding conditions?

For instance, if a participant exhibits dramatically superior performance under Technique 3, it is impossible to definitively partition the variance into that attributable to the technique itself versus that attributable to the residual learning effect. This ambiguity compromises the internal validity of the study, making it difficult, if not impossible, to draw causal conclusions. Effective research design must anticipate and control for these systematic sequential dependencies to ensure that the measured effects are reliable indicators of the treatment efficacy.

### Primary Classifications of Carryover Effects

While the term carryover effect is a broad descriptor for sequential biases, researchers commonly categorize these influences based on the specific mechanism of transfer. The two most recognized and antithetical types are the Practice Effect and the Fatigue effect, which are essentially two sides of the same coin--changes in participant state due to repeated exposure.

## Practice Effect

The **Practice Effect**, also sometimes referred to as a positive learning curve, describes a form of carryover where repeated exposure to the task or methodology results in improved performance irrespective of the specific treatment condition. As a participant completes the task multiple times, they develop proficiency, familiarity with the instructions, and often, improved motor skills or cognitive strategies relevant to the task demands.

This systematic improvement means that results collected during later treatment phases will likely be artificially inflated relative to those collected earlier. For instance, in a reaction time study, the participant might become quicker not because Treatment B is superior, but because they have learned the button layout and the rhythm of the experiment through the repeated practice of Treatment A. This systematic upward trend biases results, suggesting a benefit where only enhanced skill acquisition exists.

## Fatigue Effect

Conversely, the **Fatigue Effect** represents a negative carryover, where the participant's performance systematically declines across successive treatment conditions. This decrement in performance is attributed to the cumulative toll of repeated effort, resulting in mental exhaustion, physical strain, or loss of motivation.

Returning to the card memorization example, while initial practice might boost performance, prolonged exposure to mentally taxing tasks can lead to cognitive drain. As participants are forced to use Technique 3 and Technique 4 sequentially, their ability to concentrate and process information might diminish simply because they are mentally tired from performing the previous tests. Consequently, the later treatments receive lower, unfairly biased scores, leading to the erroneous conclusion that these techniques are less effective when, in reality, the measurement is confounded by the state of fatigue.

## Types of Carryover Effects

### Practice Effect

Participants perform better during later treatment conditions because they've had time to practice and improve.

### Fatigue Effect

Participants perform worse during later treatment conditions because they're tired or fatigued from previous treatment conditions.

## Other Forms of Sequential Bias

While practice and fatigue effects are the most common, other sequential biases also contribute to the broader carryover effect. These include differential carryover effects and sensitization.

**Differential Carryover:** This occurs when the effect of one specific condition (A) is significantly stronger or different than the effect of another specific condition (B) on the subsequent condition (C). For example, Technique 1 might sensitize the participant in a way that dramatically helps Technique 3, whereas Technique 2 might have no lasting residual impact on Technique 3. This non-linear interaction makes analysis extremely complex.

**Sensitization:** Participants may become increasingly aware of the experimental hypothesis or the manipulation itself after being exposed to multiple conditions. This awareness can change their behavior or response strategies in later trials, leading to artificial effects based on expectancy rather than the treatment itself.

## Strategies for Mitigating Carryover Effects in Design

Because carryover effects pose a fundamental threat to the validity of within-subjects research designs, researchers must proactively implement rigorous methodological strategies to minimize or distribute these systematic biases. The goal is not always to eliminate the effect entirely, which is often impossible, but rather to ensure that the effect is balanced equally across all conditions so that true treatment differences can emerge.

### Technique 1: Implementation of Practice Trials and Warm-ups

A targeted approach to combat the Practice Effect involves integrating extensive practice or warm-up periods before the official data collection begins. By giving participants sufficient time to familiarize themselves with the testing environment, equipment, and core task requirements, researchers can help the initial rapid learning curve stabilize.

If the participant reaches a stable level of performance--a plateau--during the warm-up phase, the subsequent measurement trials are less likely to be contaminated by further skill acquisition. This ensures that when the true experimental treatment is introduced, the observed changes in performance are genuinely attributable to the manipulation and not merely the ongoing development of task proficiency.

### Technique 2: Strategic Task Length and Rest Periods

To mitigate the negative impact of the Fatigue effect, researchers must carefully design the structure and duration of the experimental protocol. Tasks that are excessively long, monotonous, or mentally demanding dramatically increase the likelihood of participant exhaustion and resulting performance decline in later trials.

This minimization strategy focuses on two elements: first, ensuring that individual task blocks are concise and highly focused; and second, incorporating substantial rest periods or breaks between successive treatment conditions. These breaks allow for psychological recovery and cognitive refreshment, thereby reducing the likelihood that cumulative tiredness will act as a major confounding variable.

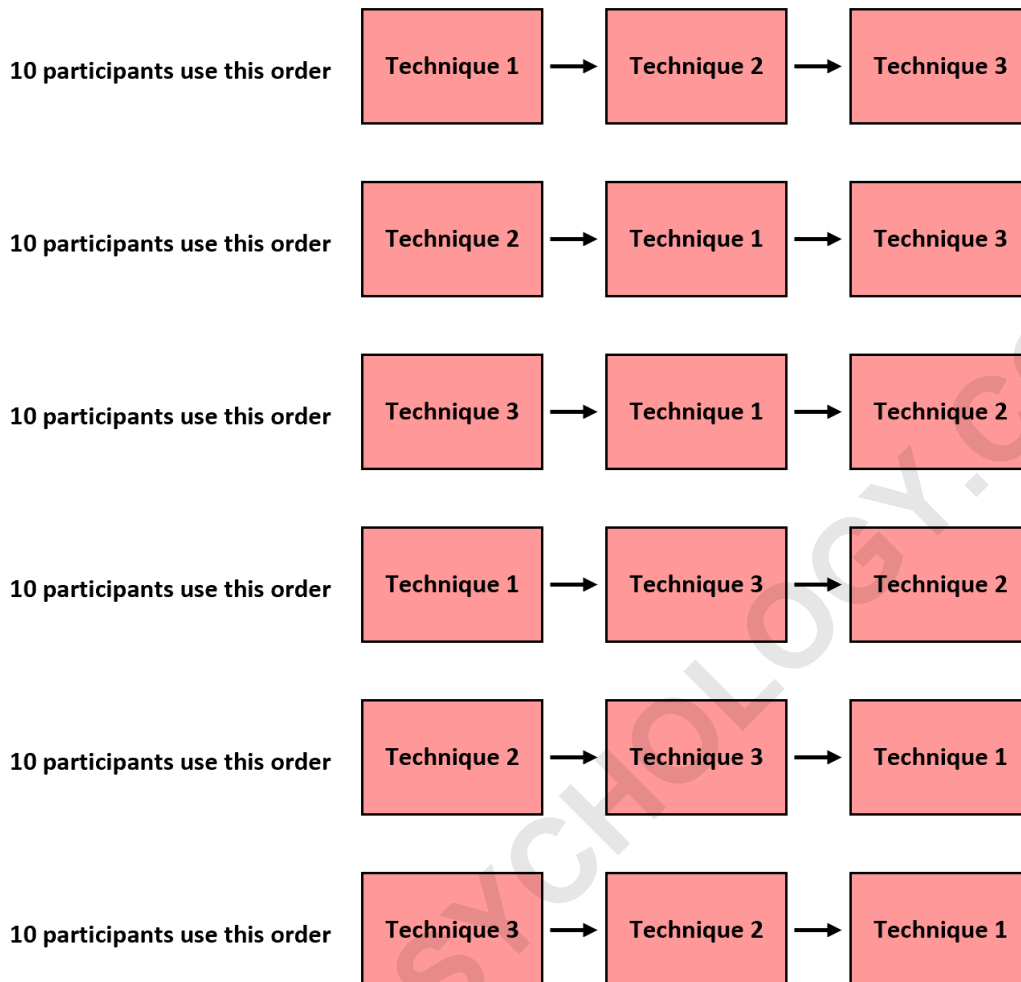
### Technique 3: Employing Counterbalancing Techniques

The most powerful statistical method for controlling general carryover effects is Counterbalancing. This technique systematically varies the order in which participants receive the different experimental treatments, effectively distributing the potential biases (such as practice or fatigue) equally across all conditions.

In a fully counterbalanced design, if there are three treatment conditions (A, B, C), participants would be randomly assigned to all possible permutations: ABC, ACB, BAC, BCA, CAB, and CBA. By ensuring that an equal number of participants complete each possible sequence, the average performance for treatment A is influenced by an equal amount of practice/fatigue as the average performance for treatment B, allowing the true treatment effect to be isolated through statistical averaging.

For example, if researchers are testing three techniques (1, 2, 3), a set of 60 participants might be divided into six groups, with 10 participants receiving the order 1-2-3, 10 receiving 2-1-3, 10

receiving 3-1-2, and so on.



## Limitations and Alternatives to Full Counterbalancing

While full counterbalancing provides the most robust control over linear order effects, it becomes logistically prohibitive as the number of treatment conditions (N) increases. The number of required sequences grows factorially ( $N!$ ), meaning a design with four conditions requires 24 unique sequences, and five conditions require 120. Implementing every single order equally can be excessively time-consuming, expensive, and impractical, particularly with limited participant pools.

In situations where full counterbalancing is infeasible, researchers often turn to partial counterbalancing methods, such as:

**Latin Square Design:** This design ensures that every condition appears equally often in every serial position (e.g., first, second, third) and, crucially, that every condition precedes and follows every other condition exactly once. This dramatically reduces the required number of sequences

while maintaining strong control over basic order effects.

**Randomized Blocks:** In this simpler method, each participant receives a unique, randomly determined sequence of treatments. While less systematic than the Latin Square, it assumes that randomness will distribute the carryover effects evenly across a large enough sample size.

When carryover effects are known to be severe or permanent (e.g., surgical interventions or irreversible learning), a between-subjects design, where different groups receive different treatments, is often the only viable alternative, sacrificing efficiency for greater internal validity.

## Conclusion and Further Reading

The carryover effect represents one of the most significant threats to internal validity in sequential experimental designs. It compels researchers to move beyond simple treatment application and consider the dynamic, cumulative psychological state of the participant throughout the study. By rigorously employing mitigation strategies--such as integrating appropriate warm-up periods to absorb initial learning, scheduling sufficient breaks to combat fatigue, and utilizing sophisticated randomization methods like counterbalancing--scientists can isolate the true efficacy of their interventions from the noise introduced by serial exposure.

A deep understanding of practice effects, fatigue effects, and differential carryover is indispensable for anyone designing methodologically sound research, ensuring that the conclusions drawn are accurate reflections of the treatment variables rather than artifacts of the experimental sequence.

The following tutorials provide an explanation for other common effects in experiments: