

SUMMARY

1. Introduction

In the empirical sciences, research studies aim to generate and test hypotheses through systematic observation and experimentation. Knowledge accumulates by testing increasingly specific hypotheses, building on existing results. Such scientific progress requires studies to be conducted rigorously, so that when they are repeated their results will be reasonably similar. Over the past few years, however, several systematic series of replication studies have been unable to reproduce many important results, even when applying lenient definitions of reproducibility. This has led to a debate within the scientific community about the way science is currently being conducted and the role of replication studies. This report analyses the causes of non-reproducibility, assesses the desirability of replication studies and offers recommendations for improving reproducibility and for conducting replication studies.

2. Concerns about and strategies to improve reproducibility

A replication study is a study that tries to repeat an earlier study, using similar methods and conducted under similar circumstances, to determine the reproducibility of the earlier study's results. Reproducibility is defined as the extent to which the results of a replication study agree with those of the earlier study. If the results of both studies agree, then the results of the earlier study are considered to have been 'reproduced', thereby increasing the likelihood that the results are valid. However, the results of replication studies in various empirical scientific disciplines are often not in agreement with those of the original studies, indicating that disciplines as a whole may be subject to a substantial degree of non-reproducibility. Studies with non-reproducible results can jeopardise scientific progress, waste resources, harm individuals and society, and erode public trust in science. There are various factors – for example, related to study methods, study reporting and the underlying incentive system for researchers – that can lead to non-reproducibility. These factors can and should be eliminated as much as possible.

3. The desirability of replication studies

Replication studies can benefit research in two major ways. First, replication of individual studies can help to allay doubts about their results or their proper execution. This is especially important if these results have, or could have, a major impact on scientific progress or on meeting societal goals, or if incorrect results will lead to a waste of research resources. Whether a replication study is the best strategy in such cases also depends on the feasibility and costs of such a study compared to alternative strategies, such as conducting another, original study. Second, systematic series of replication studies are necessary to identify the extent to which results in a particular field are reproducible, the underlying causes of non-reproducibility, and the effectiveness of measures taken to improve reproducibility. The desirability of replication series depends on how much is already known about reproducibility and on the extent to which improving reproducibility is desirable compared to other investment targets for research funds.

4. Replication studies in practice

Replication studies appear to account for a small fraction of all published literature, but reliable data are lacking. Several disciplines (including preclinical animal research, clinical research, experimental psychology, genetic epidemiology and biochemistry) have taken important steps towards improving reproducibility and developing good replication practices. This has required a significant effort on the part of the research community with proper incentives from stakeholders such as scientific journals, institutions and funding agencies.

5. Barriers to and strategies for conducting more replication studies

Researchers currently face multiple barriers to conducting replication studies: studies are often not reported in sufficient detail, making it impossible for other researchers to design a proper replication study; researchers may be unsure about the right design for a replication study and the interpretation of its results; and researchers do not always appreciate the value of replication studies and may find it difficult to get them funded and published. Three broad strategies can help establish the right conditions for replication studies: improving information-sharing about original and replication studies; improving knowledge about when and how to perform replication studies; and creating better incentives for replication studies.

6. Conclusions and recommendations

The first step towards improving reproducibility is for empirical disciplines to assess the degree of non-reproducibility within their field and its underlying causes. The Academy is of the opinion that improving reproducibility, wherever it is found to be unsatisfactory, is extremely important. The Academy therefore recommends that researchers, funding agencies, journals and institutions should adopt the following measures:

- *Improve study methods.* Researchers should conduct research more rigorously by strengthening standardisation, quality control, evidence-based guidelines and checklists, validation studies and internal replications. Institutions should provide researchers with more training and support for rigorous study design, research practices that improve reproducibility, and the appropriate analysis and interpretation of the results of studies.
- *Improve study reporting.* Funding agencies and journals should require preregistration of hypothesis-testing studies. Journals should issue detailed evidence-based guidelines and checklists for reporting studies and ensure compliance with them. Journals and funding agencies should require storage of study data and methods in accessible repositories.
- *Create proper incentives.* Journals should be more open to publishing studies with null results and incentivise researchers to report such results. Rather than reward researchers mainly for ‘high-impact’ publications, ‘innovative’ studies and inflated claims, institutions, funding agencies and journals should also offer them incentives for conducting rigorous studies and producing reproducible research results.

The Academy also concludes that replication studies are a normal and essential part of science. Replication studies are an important tool for improving scientific knowledge, scientific methods and the functioning of scientific disciplines, and they should be conducted more frequently and systematically than is currently the case. Researchers should make careful assessments of the desirability of replication studies and consider the expected costs and benefits of conducting such studies compared to alternative approaches. To allow researchers to conduct replication studies when indicated, we recommend the following measures:

- *Improve information-sharing.* The above recommendations on study reporting also hold for replication studies: funding agencies should require preregistration of hypothesis-testing studies, and journals should issue reporting guidelines and require repositories for data and methods.
- *Improve know-how.* Researchers should share best replication practices and the

resources (e.g. methods, software, materials, samples, detailed analysis plans) required to conduct a particular replication study. Institutions should teach researchers how to design replication studies and assess reproducibility.

- *Create better incentives.* Funding agencies should increase funding for replication studies (e.g. by setting up programmes that allocate money specifically to replication studies and/or by requiring researchers to include replication activities in their individual proposals). Journals should encourage the submission of replication studies. Institutions should properly credit replication studies in career evaluations.