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The Non-Scientist's Guide to Reading and Understanding a Scientific Paper

It's not as difficult as you think. Well, maybe it is. But reading scientific articles will help you make more informed decisions, and better understand and participate in the public debate about important scientific issues

Illustration by Señor Salme for Endpoints

Highlights:

→ More than 2.5 million new English-language scientific papers are published each year in more than 28,000 peer-review journals.

→ While many are paywalled, there are also prestigious open-access journals where you can read articles for free.

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→ Reading articles will help you make more informed
decisions in the areas of life that concern you, and better
understand and participate in the public debate about
important scientific issues.
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→ Here are the basic steps: focus on the big picture the
scientists are addressing; read the Abstract, Introduction,
and Discussion, in that order; think critically about the
conclusions the scientists make; conduct follow-up research.
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→ For practice, we provide a link to a popular scientific
paper on light-emitting e-readers.
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We live in a golden age of scientific research. The top five countries in scientific research and development—the U.S., China, Japan, Germany, and South Korea, respectively—spend over $1 trillion on it each year. But where do all the resulting discoveries and *eureka!* moments go? Eventually they may find their way into textbooks or form the foundation of a life-saving therapeutic, but first most of them they go onto the page, in a scientific article.

According to a report by the International Association of Scientific, Technical and Medical Publishers (available for download here), more than 2.5 million new English-language scientific papers are published each year in more than 28,000 verified journals that use the stringent "peer review" system, whereby multiple scientists who are specialists in the relevant field of study provide a critical and in-depth review of a new paper. The process takes months and is overseen by a journal editor and several reviewers who read the study; only once the editor is convinced the author has addressed notes from peer reviewers in such categories as originality, importance, manner of presentation, and critical flaws, is it accepted into a journal.

The most common form of scientific article is a *primary research article*, an original report of research which chronicles an experiment in such a way that it can be replicated and the results reproduced by other scientists—core tenets of the scientific method. (Another type is a *review article*, where several primary research articles are discussed and their findings placed in greater context.)

The internet has made disseminating that sea of scientific information easier than ever, one result of which is a deluge of "A Groundbreaking New Study Finds…" headlines on websites and in magazines. While

overly reductive reporting on scientific breakthroughs is not new to the media—the general public has at times felt whipsawed by science and health reporting for decades—the total quantity of scientific research and media sources is only increasing. More often than not, those articles grab the biggest "finding" and speculate on what it might mean a decade into the future, which often falls short of explaining the study in context and helping readers form an educated understanding of what the scientific research actually showed.

So how do you distinguish hyperbole from scientific evidence? By reading the papers yourself.

That's not easy, even for scientists, who readily admit that reading these papers can be akin to torture. (A recent article in *Science*, enumerating the steps of reading a paper, included "fear," "regret," "bafflement," "distraction," and "rage.") Rather than charging headfirst into several thousand words of science-speak, follow this plan of attack for primary research articles. With a little practice, you can do more than just understand them: you can replace conventional wisdom with knowledge, make more informed decisions in the areas of life that concern you most—health, fitness, and diet, for example—and better understand and participate in the public debate about important scientific issues.

Editor's Note: To illustrate the process, we've chosen a popular scientific paper published in 2015 in *Proceedings of the National Academy of Sciences*, "Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness." You can access the paper for free here.

1. Locate the Article

You'll likely begin your search one of two ways: either by tracking down a paper cited in a news story (in which case: Google), or by searching for papers on a topic that interests you. The highest profile sources of peer-reviewed articles are *Nature*, a British journal, and *Science*, its American competitor. But there are credible journals for every branch and sub-branch of science. The best place to find those is on PubMed.gov, a database holding more than 27 million citations to credible journals.

Note that many scientific papers are not available for free. In a 2015 list of the most influential primary research papers by AltMetric, 42 were open access and 58 were paywalled. Paywalls are a source of frustration for a large swath of the general public (including academia, industry, and media), who argue that open access to research hastens innovation—and indeed that the public has a right to access the research it funds with tax dollars. This friction between publishers and everyone else has given rise to a variety of responses, including open-access journals, the search engine Sci-Hub, and policies from funding sources, like the Bill & Melinda Gates

Foundation, that require research to be disseminated to the public free of charge.

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Before Your Start: The Anatomy of a Primary Research Article
Abstract: A condensed version of the article including the problem scientists were looking into, related work in the field, why this paper is new and novel, the most important findings, the overall conclusion, problems that occurred during the experiments.
Introduction: Scientists cite previous research in the field and explain their hypothesis in broad terms. **Methods and Materials:** A precise description of the experiments such that they can be replicated by other scientists.
Results: All the important resulting data from the experiments.
Discussion/Interpretation/Conclusion: How the authors interpret the data.

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2. Wrap Your Head Around the Big Picture

Read the Abstract for the bottom line of the study and then dig into the Introduction. While the Abstract can be dense prose, the Introduction is where the authors provide big picture context for the study and explain previous research in the field, often in a narrative style that's easy to follow. It's helpful to imagine each scientific paper as a single chapter in a long novel; this section is where you'll gain an understanding of what chapters came before. It's also where the authors broadly explain their hypothesis—or, where they're guessing their own chapter will lead.

You want to come away from the Introduction with an understanding of the central problem the particular field of science is dealing with, as well as a subset of questions (related to the problem) that the authors of the paper plan to address. They will offer a hypothesis about the answer to those questions and suggest a plan of attack—the experiment(s)—for investigating whether it's true.

In the e-reader article, the central problem is, *How significantly are human sleep cycles, and therefore health, affected by technology?* The authors explain that the "previous chapters" in this field have

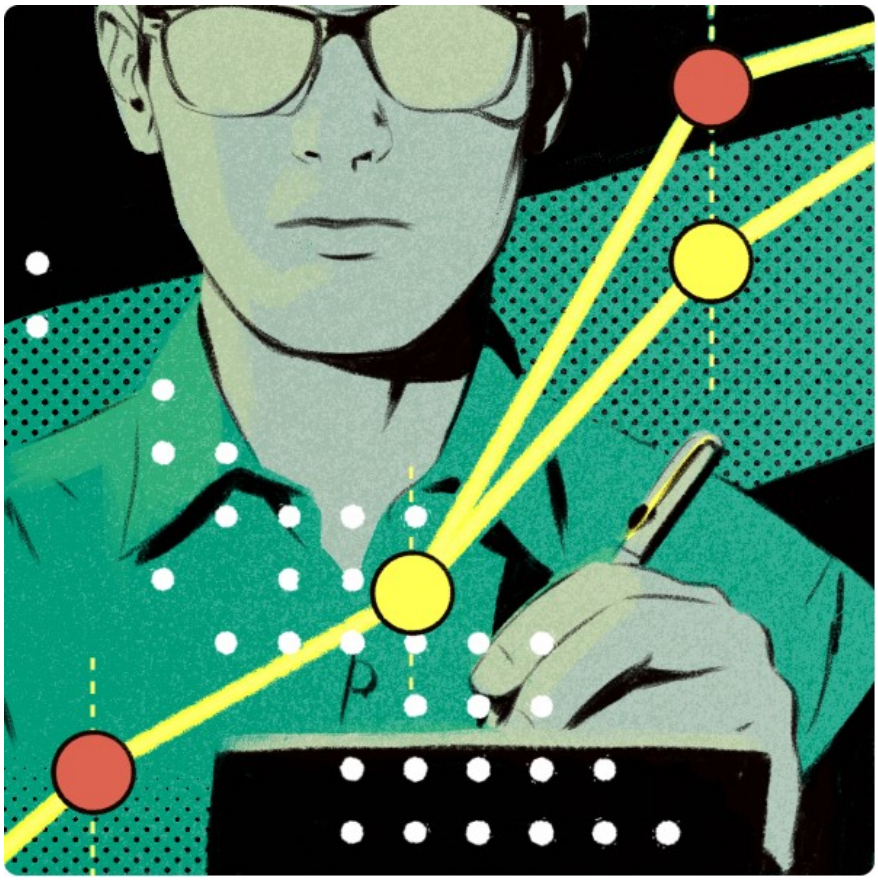
discovered that a circadian timing system directly affects when and how we sleep, and that the circadian cycle is directly affected by exposure to light in the early evening and nighttime, which suppresses the release of melatonin, a hormone that tells our bodies to sleep; the resulting lack of melatonin acutely increases alertness. The specific questions posed in the paper are, *How does the light of an e-reader's screen affect the circadian rhythm of test subjects, how does that affect the quality of their sleep and their alertness the next day?*

3. Skip Ahead to the Conclusion

The Methods and Results sections come next, but skip ahead to the Discussion, alternatively called the Conclusion or Interpretations, which will summarize the findings—at least what the authors think they have showed—in a digestible way. This section includes how the authors interpret the data from their experiment and what it means for their original hypothesis. At the very end they will speak to how their findings change our understanding of the bigger picture, those surrounding chapters in the novel that makes up the scientific field's entire progress. Keep in mind that scientific articles have limitations, often acknowledged in the paper, which require further research.

The scientists behind the e-reader study address both the larger problem and their unique questions in their Conclusion. "These results indicate that reading an LE (light emitting) eBook in the hours before bedtime likely has unintended biological consequences that may adversely impact performance, health, and safety," they write. Specifically, based on their data they suggest that beyond just disrupting single instances of sleep, the light from e-readers may lead to a pattern of sleep deficiency by delaying the circadian timing system, which in turn reduces the REM sleep that would otherwise happen closer to waking.

And they describe a harrowing big picture given these findings: teenagers are spending upwards of 7.5 hours a day consuming media on readers, phones and computers, much of which happens in the evening and nighttime. The authors are especially concerned because studies of night shift workers have found a relationship between chronic suppressed nocturnal melatonin release and colorectal, breast and prostate cancer.



4. Understand the Results

The Results section and its attending figures and tables present the data without interpretation from the paper's authors. As a result, this section will usually be the most difficult for the non-scientist.

A few statistics terms will help you navigate the data: "significant" and "non-significant." This basic statistics terminology is used by scientists to describe events that could be the result of random chance ("non-significant") versus data that could represent meaningful discoveries ("significant"). If you're not familiar with statistics, consider reading a primer like this one from *Harvard Business Review*. Be aware that the Results section (and Methods) is sometimes challenging even for other scientists who are reading outside their field of expertise.

Pay attention to the figures and charts, which pack a lot of clear information into visuals. Read the captions closely, since they tend to explain the results with simple, clear language. And circle back to simplest questions: *What is being measured? Given what you read in the Introduction and Discussion, what do the data illustrate?*

The e-reader study includes several results from its experiment that support the interpretation in the Discussion section, all fairly easily understood using the figures and captions. For example, that after five consecutive days of reading using electronic light, the e-reader group's melatonin onset levels were significantly suppressed in the evening when compared to the group reading traditional books. Those using the e-reader also took an average 10 minutes longer to fall asleep than those in reading books. And those using e-readers had significantly less REM sleep on average.

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Assessing the Subject: Cells, Model Organisms, and Humans

A small but important detail: What are an experiment's test subjects? There's a big difference between the implications of results found studying model organisms (non-human species) or in human cells *ex vivo* (outside the body) versus results discovered in clinical studies (humans) — one that articles in the news usually don't usually mention in the first few paragraphs.

While research cells and animals is vital for advancing our understanding in various fields of science and can produce groundbreaking results, these results don't always carry over to humans. Scientists can reliably extend the life of mice by 30 percent, but that doesn't mean it can be done in humans.

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5. Understand the Experiments

"Materials and Methods" is where the authors describe their experiment in enough detail that they can be replicated by other scientists. This is vital for the entire field of science, which is built on reproducible data. It also makes this section challenging and perhaps less important to understand for non-scientists. However, you'll be rewarded for working toward a general understanding of the Methods section since plenty of experiments are poorly-designed, particular in the areas of randomization, blinding, and sample size. If you are curious about how the experiment was carried out, expect to spend time here looking up challenging terminology.

6. Recognize This Is Just the Beginning

In the final moments of the Conclusion and you may find a call to action: Scientists often recommend what they believe should be done next. "Because technology use in the hours before bedtime is most prevalent in children and adolescents," the authors of the e-reader study write, "physiological studies on the impact of such light exposure on both learning and development are needed." If you're interested in learning more you can turn to the References section for further reading, or even contact one of the authors with questions. After all, a lot of scientific research is funded with public money, and the science community is surprisingly accessible. Odds are the author will be happy to discuss a topic that's likely his or her lifelong passion.

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Get Started with Eight Important Open Access Journals

eLife: A life sciences journal edited by Nobel Laureate Randy Schekman and established by the Howard Hughes Medical Institute, Max Planck Society, and Wellcome Trust.

Cell Reports: The open access arm of Cell Press, which publishes some of the most reputable journals, including *Cell*, *Cancer Cell*, and *Cell Metabolism*.

Journal of the American Chemical Society: A leading chemistry journal published by the American Chemical Society.

Journal of Nutrition: A peer-reviewed journal published by the American Society for Nutrition.

Nature Communications: The open access arm of the Nature Publishing Group, which publishes roughly 70 journals. This one covers the natural sciences.

New England Journal of Medicine: The oldest, and one of the most prestigious, peer-reviewed medical journals. Articles are available for free six months after they are published.

PLOS Biology: One of seven open access journals published by the Public Library of Science.

Royal Society Open Science: The journal published by the Royal Society, which is the Academy of Sciences for the UK and Commonwealth of Nations.