

How to Evaluate a Scientific Research Article

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The world of scientific research articles and journals can be a daunting prospect for any new researcher, let alone the practising eye care professional. However, there is a growing need to look at and evaluate published scientific research, since this offers the primary source of answers for an ever-increasing trend towards providing evidence-based healthcare.^{1,2} Whilst there are several resources that are available to the writer of research articles,³⁻⁷ few exist to help the non-expert reader to make adequate sense of published research.^{8,9} Furthermore, although the vast majority of research articles are now subjected to a peer review process, some research might not meet expected standards, perhaps due to improper conduct (e.g. plagiarism, falsification, fabrication)¹⁰ or commercial/outside pressure. This article provides an overview of how to evaluate a research article, with the hope that eye care professionals will gain the necessary basic understanding of how to extract relevant scientific information as part of their ongoing professional development.

There are many types of articles that are published in scientific journals but these generally take one of two forms. Literature-based articles review the research that has been conducted in a particular area or topic, whereas experimental articles describe the findings of a practical study, clinical trial, or survey, and typically report the findings using an “Introduction / Methods / Results / Discussion” or “IMRAD” structure.^{11, 12} Although literature-based articles are an excellent starting point to gain an overview of a topic, the latter type of article is perhaps more pertinent for contributing to evidence-based healthcare. As such, the present article concentrates on evaluating this type of paper.

Searching for Articles

Finding the relevant articles is naturally the first step on the road to evaluating and learning from scientific research. There are several searchable databases that collate research articles published in a myriad of journals; these include The Cochrane Library (this comprises three, free, online

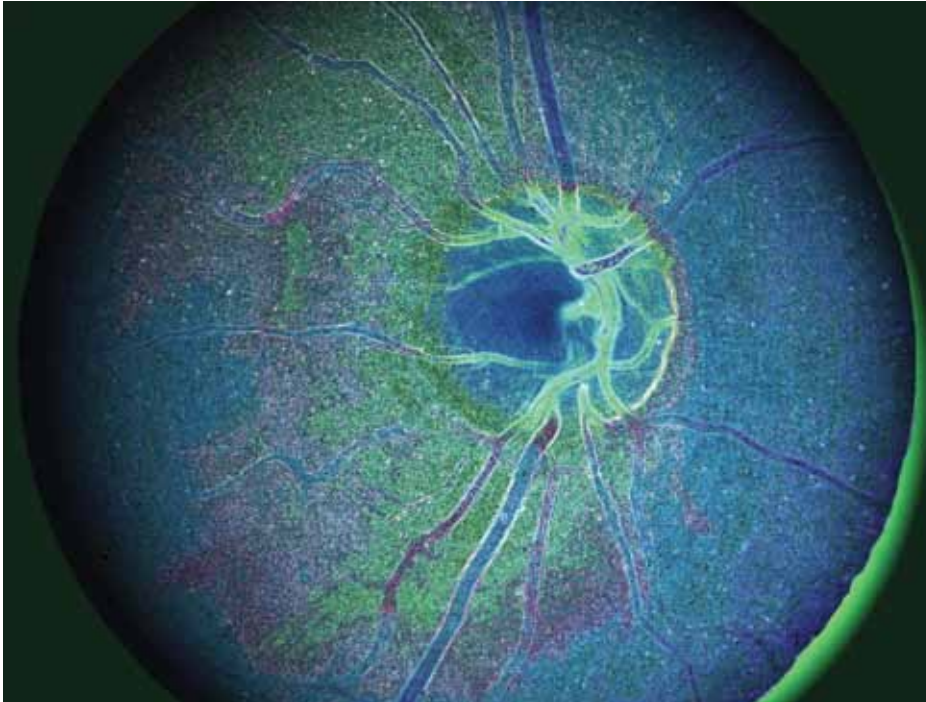
databases representing a worldwide collaboration, which provide healthcare information for the busy practitioner), PubMed Central (U.S. National Library of Medicine and the National Institutes of Health, Bethesda, USA), ScienceDirect (Elsevier, Amsterdam, Holland), and Ingenta (Publishing Technology Plc., UK and USA) amongst others. Databases such as Turning Research Into Practice (TRIP) are very relevant for evidence-based healthcare, as they focus on clinical evidence that is relevant to clinical practice. In fact, simple searches on Google Scholar can also be a very useful starting point, as a list of individual articles will be provided and each will have links to other articles that have cited that particular paper, allowing for branching out of your search. Likewise, searching through journals that have titles such as ‘Annual Reviews of ...’ or ‘Advances in ...’ will provide useful general review papers, whose bibliography can be used to branch out the search for articles.

Knowing a little about the topic of interest and being familiar with the names of well-known researchers in the field will go a long way to ensuring that

you can identify the relevant papers, by using title and/or author name searches. Keyword searches of the database(s) will also be essential to help to locate articles written by unfamiliar but equally important authors. Furthermore, searching for articles that have been published in more recent years (e.g. within the past 5 years) will ensure that you will be reading the most up-to-date information. However, certain “landmark” papers will remain justifiably relevant even decades after first publication; for example, the article written by Holden & Mertz¹³ describing the critical oxygen levels required to avoid corneal oedema in contact lens wear was first published in 1984 but has been cited over 300 times since and is referred to for clinical relevance even today.

Abstracts

Aside from the obvious indications of relevance that can be obtained from the title, the article’s abstract is perhaps of greater importance at this stage, and most journal database searches will provide free access to this. The abstract provides an overview of the research article, and again usually follows the IMRAD structure. This can be a good place to start to get a general feel for the quality of the paper and research, as a cursory read should make the salient points of the research evident. The abstract should be clear and concise (many journals will automatically stipulate a maximum word count of 250 or 300 words), and it should display evidence that: (i) there was a primary (and perhaps a secondary) aim or “objective” to the research, (ii) there was a logical method followed in performing the research, (iii) results were obtained and were subjected to statistical analyses, and (iv) the author(s) drew conclusions directly from the results of the study and that these findings answered the primary



(and any secondary) objectives.^{14, 15}

An example of a good abstract is that written by Medeiros et al.¹⁶ for their study investigating the relationship between intraocular pressure (IOP) and progressive retinal nerve fibre layer (RNFL) loss in glaucoma. There is a clearly defined goal of the study, which is evident from the title, with a brief description of the measurement of RNFL loss using a scanning laser polarimeter, in patients diagnosed with glaucoma; their study revealed a significant loss in RNFL with increasing IOP, as supported by statistical analysis (significance, or “p” values, are reported), and the authors therefore conclude not only that IOP perhaps does cause structural damage in glaucoma but that the scanning laser polarimeter technique is useful for monitoring such patients.¹⁶ In contrast, the abstract written by Zimmerman et al.,¹⁷ for their study evaluating the safety and efficacy of Timolol in paediatric glaucoma, is not very informative since there are no reports of the actual IOP measurements and no evidence of any statistical analysis; unsurprisingly, no clear conclusions are reported either. However, it must be borne in mind that such abstracts are very uncommon today since most journals insist on a minimum level of detail and quality from authors. Having established this evidence of quality, the reader can then delve into the main manuscript with a certain minimum assurance.

The Background

The introduction or background to a scientific research article, even one that reports a clinical trial or experimental study, typically provides a brief review of the literature on the topic in question. This is aimed at explaining current knowledge of the topic and helps lead the author(s) to propose the research question that forms the focus of their study. It is important for the reader to evaluate the extent of this review, to ensure that the author(s) have thoroughly researched the area, have displayed a sound understanding of the topic, and have obtained adequate support from this to justify the need for the research reported.¹⁸ In turn the author(s) should end with a clear objective for their research, whilst an insight as to the novelty of the research can also be gained.

Readers should look at the articles that the author(s) have referenced in the introduction to ensure that they are up-to-date, relevant, and are expansive enough to cover a wide variety of publications. A simple look at the bibliography at the end of the article, to see whether the titles bear any sort of resemblance to the point made in the text or not, will help the reader to establish whether the author(s) have paid due care and attention to their literature review. This will also serve to confirm the author(s)' knowledge and expertise in the area. If this is not the case, then you cannot be certain that

the same level of care will have been applied to the actual study reported. Readers should also be careful of websites that may be cited as references, as they may lack certain details and may not have easily identifiable credentials.

It is also important to ensure that the author(s) have provided an unbiased review of the literature. Again, a look at the references might give an indication of this. For example, an author that has predominantly cited his/her own previous work might not be seen to be accepting of other research published in the area. Naturally though, a well-seasoned researcher is likely to have many publications in their research area and it will be logical for them to cite their own work. However, the author(s) must display evidence that they are aware of other people's work too and that they have considered the implications of that work on their own.

Readers should also take the opportunity here to ensure that the information provided in the literature review fits with their own knowledge and understanding of the topic. If it does not then one may question whether the author(s) are clear in their own minds about what it is they wish to achieve in their research, or it may mean that the reader themselves perhaps lacks sufficient background knowledge, in which case it is recommended that you read around the subject matter a little more first, e.g. from books and literature review papers, before tackling the article further.

The Methods & Materials

Although many would consider the outcomes of a study to be the most important aspect of a research article, the way in which the research was conducted is of equal, and perhaps even of greater, importance. This is because one needs to be certain that the findings are based on a sound and accurate scientific study design; if the study was not performed accurately and correctly, then in turn the results cannot be deemed to be accurate and correct. Indeed, the article in question may be expanding on a previous study that has been conducted and, although not novel, the article may therefore be reporting the findings of a more rigorous study design.⁹

A fundamental requirement of the

methods section is that sufficient information and detail should be provided, in a clear, logical, and coherent manner, to allow for the entire study to be replicated by others.¹⁹ It is important for readers to satisfy themselves of this since it is the only way that other people can conduct similar investigations, in order to be able to corroborate or disprove the findings reported. Other key questions that readers ought to ask themselves whilst reading the methods section of an article are briefly described below.

The Study Design

The reader should be satisfied that the design of the study was suitable for the research aim. There are several study designs that can be followed and the terminology used to describe these, which readers ought to familiarise themselves with, is summarised in Table 1. Although this relates to experimental studies, as per the focus of this article, it should be borne in mind that such designs may not be entirely appropriate for observational studies, which are experimental in nature but offer less control since they are based on real-life events that occur naturally. For example, analysis of the relationship between vision and driving accidents is only ethically acceptable if conducted retrospectively, by assessing vision standards of drivers involved in accidents as they occur naturally on real roads; the alternative of conducting experimental trials using a driving simulator may offer more experimental control but they are not as realistic.

Note that some of these study designs can be combined. For example, in their study investigating the effects of oral treatment with omega-6 fatty acids on subjective symptoms and ocular surface signs in patients with contact lens-associated dry eye, Kokke et al.²⁰ used a randomised, double-blind, placebo-controlled design, whereby participants received either evening primrose oil (containing omega-6 fatty acids – the treatment) or a placebo (olive oil); participants were randomly assigned to be in one of the two groups. Neither the participants could determine which treatment they had received, since the two tasted similar to each other, nor were the investigators aware of which

medication (treatment or placebo) participants were taking; a third party not directly involved in the study was aware of and documented which groups and treatments participants were assigned to, for later analysis. This is an ideal approach for this study since participants could not bias their subjective opinions of dryness, and investigators could not bias their objective assessments of the ocular surface, based on knowledge of which

treatment had been administered, in order to falsify an effect for the omega-6 fatty acids treatment.

In addition to the study design, readers also ought to ask themselves about whether the measurements made were actually appropriate to the research aim(s); below are some of the types of questions readers should think about as they read through the methods section:

- Could the author(s) have made different measurements to the ones actually made?

Study Design		Description
Group Comparison	Parallel Groups	Each test group begins the "treatment" at the same time but each test group will receive a different treatment. Results will be analysed by comparing the groups.
	Paired (Matched) Groups	Each test group begins the "treatment" at the same time but each test group will receive a different treatment. The groups will be matched for specific factors such as "age" and/or "gender" to rule out their influence on the results.
	Within-Participant	A group of subjects will receive the "treatment(s)" and results will be compared before the "treatment" to after the "treatment". This design uses subjects as self-controls, which minimises the influence of extraneous factors such as intelligence, motivation and attention.
Single-blind / Single-masked		Participants are not made aware of which "treatment" they are receiving. The investigators will be aware of which "treatment" the participants have been assigned to.
Double-blind / Double-masked		Participants are not made aware of which "treatment" they are receiving and neither are the investigators. An independent third person/party will be aware of which "treatment(s)" participants have been assigned to for later analysis.
Crossover		All subjects receive all of the "treatments", as well as being assessed at the "no treatment" stage. "Treatments" will be assigned randomly to participants and there will be a "washout" phase between each "treatment" to ensure that they do not interact with each other. Comparisons are then made between the "treatments" and "no treatment", with subjects being their own controls.
Placebo-controlled		Subjects are separated into groups that receive the "treatment(s)" and another that will receive a placebo. The placebo will not be evident to participants, as it will appear, in every possible way, to be the same as the "treatment(s)". The placebo group acts as a control.
Randomised-controlled		Participants are randomly assigned to the "treatment" group(s) or placebo group. All groups are then followed for the same specified time and the same measurements are conducted. All groups are matched for extraneous factors such as age and gender. This design is considered to be the "gold standard" of research study designs.

Table 1

Different types of research study designs (adapted from Greenhalgh⁹)

- Are the techniques and equipment used valid for the research aim?
- Could the author(s) have used more appropriate instruments/equipment?
- Were enough measurements taken to ensure accuracy of the results?
- Was the study conducted for a long enough period of time?

Ethical Approval & Consent

An important requirement for all research studies is to ensure that ethical approval is obtained and that participants are recruited after full explanation of the procedures, possible side effects and consequences of the study i.e. informed consent is attained. This is a prerequisite for all research that involves human participants. A common finding is that the author(s) will have obtained ethical approval from their own institutional review boards, although any study involving recruitment of participants from the National Health Service (NHS), for example at hospitals (as is commonly the case), must have obtained ethics approval from the local NHS research ethics committee.²¹

Looking for evidence of ethical approval can assure the reader that an independent review panel has scrutinised the research, before it was conducted, to ensure that the research is necessary, adheres to safety protocols and will not involve any harm to participants, and does not involve the use of unapproved/unlicensed equipment/procedures. Indeed, it has been shown that research ethics committees frequently identify errors in the study, particularly violations in procedures, which highlights the importance of independent review prior to implementation.²²

Readers may commonly encounter reference to the “Declaration of Helsinki”, which is a highly revered document that governs conduct for research ethics and which authors will often cite as being a guide that they used for conducting their research.²³

Participants and Power

The recruitment of participants for the research study will typically follow sets of inclusion and/or exclusion criteria. These are put in place to ensure that the right types of “subjects/patients” are recruited, to minimise the influence of

unwanted factors. For example, in their study evaluating the performance of an ‘accommodating’ intraocular lens (IOL) in an eye that received corneal refractive surgery, Aslanides et al.²⁴ recruited a patient that had previously received photorefractive keratectomy (an inclusion criterion) but had to ensure that there was no other co-morbidity such as age-related macular degeneration (AMD) or diabetic retinopathy (exclusion criteria), which would otherwise have influenced the visual outcome measures. When the author(s) follow sets of inclusion and/or exclusion criteria, all of which should be clearly listed in the article, the reader can be sure that the author(s) have made sufficient attempts to minimise systematic bias in the study.⁹ Equally, the inclusion/exclusion criteria should not result in unrepresentative samples of participants being recruited, especially if the research is to be applicable to the general wider population. For example, in their study investigating the prevalence of a variety of visual impairments and eye abnormalities in the Indian population in Oklahoma, USA, Lee et al.²⁵ necessarily included only participants of Indian origin and who were resident in this location, to gain a representative view of this demographic group, most likely for further comparisons to other ethnic groups. If, however, the study’s aim were to evaluate the general prevalence of visual impairments and eye abnormalities in Oklahoma, such an inclusion criterion of ethnicity would then not be appropriate.

As well as ensuring that a study has recruited the right type of participants, it is becoming increasingly important to display evidence that the right *number* of participants has also been recruited. The author(s) therefore need to present their calculations of “sample size estimation” and “power analysis”, which are usually conducted prior to the actual study. These calculations carry two primary purposes, both of which go hand-in-hand since one will influence the other. Sample size estimation calculations will allow the author(s) to determine the minimum number of subjects required for their study. Consequently, power analysis will then allow the author(s) to determine whether the size of the study (i.e. the number of subjects) is large enough to detect a real

effect by statistical analyses, according to the differences they expect to observe; the expected “effect size” can be estimated from clinical experience or can be based on the findings of previous similar research in the area.²⁶ In essence, these calculations aim to ensure that the study is large enough to detect a significantly real effect and also to ensure that no more subjects are recruited than necessary, so as not to waste time and resources. Different statistical tests that are to be performed in the analysis will require different types of sample size estimation and power analysis calculations to be done. It is beyond the scope of this article to describe each of these, but the interested reader can find further information in the excellent text by Cohen.²⁸

Statistical Analysis

Understanding statistics can be a very intimidating task even for those actually conducting the research. However, readers need not be statisticians or possess specialist mathematical skills in order to be able to evaluate the statistical rigour of a research article. The basic knowledge of statistical tests that readers should begin with is:

- Statistical tests are generally grouped into two categories. Parametric tests are used when data follow a normal distribution whilst non-parametric tests are used when data do not follow a normal distribution; the latter are considered to be less powerful than parametric tests, but tend to be a safer option if a normal distribution cannot be assumed.²⁹
- Statistical tests involve hypothesis testing and the outcome is typically a probability level or “p-value”, which indicates the likelihood that the difference observed will occur by chance. Usually, the hypothesis being tested is that there is no significant difference between the groups of “treatments” being assessed. Where a p-value of 0.05 (5%) or lower is obtained, this indicates that there is a 5% (or less) probability that the observed difference is due to chance i.e. it is significantly likely that the difference is a real effect.
- If one variable is expected to be higher or lower than another, this requires the use of a two-tailed test. Where a difference in one direction only is expected then a one-tailed test is used.³⁰

For example, it might be expected that IOP is only higher in patients with glaucoma compared to those without, in which case a one-tailed statistical comparison can be made.

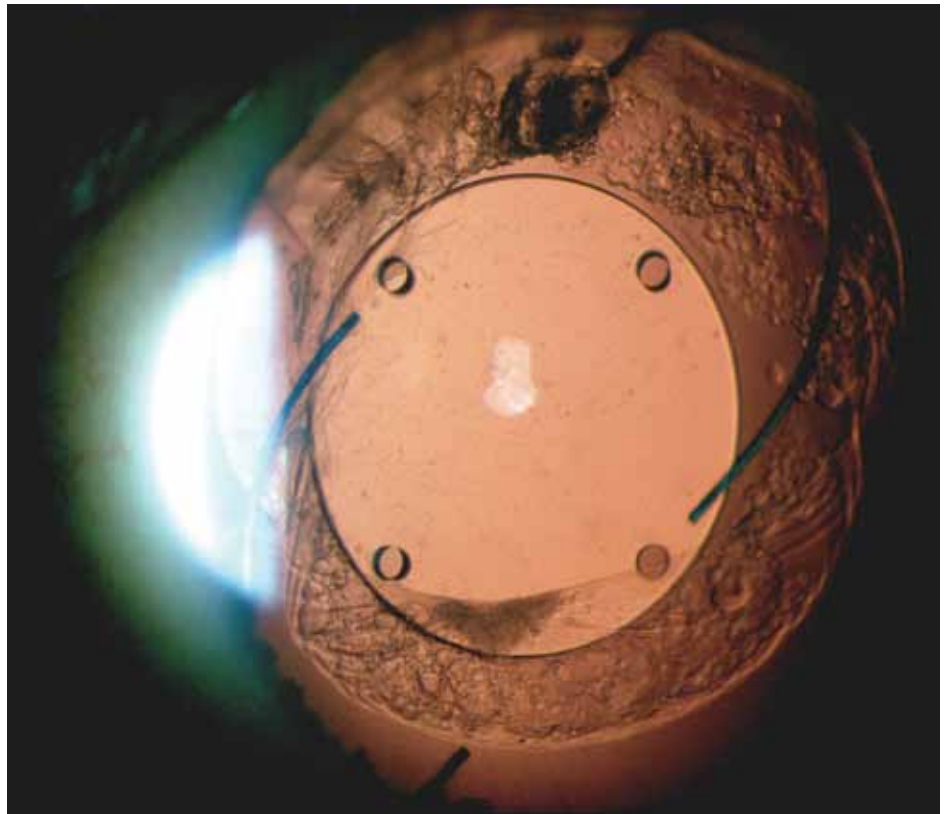
Equipped with this knowledge, there are then really only two important questions that a reader needs to ask about the research being evaluated: (a) were any statistical analyses conducted, and (b) were the correct statistical tests applied. These questions are important since statistical analysis is the only method available for assessing whether any changes or differences observed in the data are actually meaningful, whilst the application of incorrect statistical analyses will lead to incorrect and/or irrelevant conclusions being drawn.³¹ The reader does not need to know in-depth details of all statistical tests in their entirety, but you should at least understand the nature and purpose of commonly encountered statistical tests, in order to evaluate the appropriateness of the methods used by the author(s). Table 2 can be a useful basic guide to refer to.

The Results Section

The results of the research are perhaps the most interesting part of an article, as it is here that the reader will learn about the outcomes of the research. The section should begin with a description of the demographics of the participants recruited, and should include at least the following information in order to display the author(s)' success at achieving the earlier power analyses and sample size estimations:

- Total number of participants recruited
- Mean age of participants \pm standard deviation, and range (maximum and minimum ages)
- Proportion (and numbers) of males and females recruited
- Mean refractive error \pm standard deviation (usually for all optometry-related studies)

Authors can use a wide variety of techniques to display the results, the most common being tables and graphs. A brief description of the results should also be provided in the text, with the most important trends or findings highlighted. It is typical for mean values to be reported along with standard deviations (indicating the spread of data). It is also important that all statistically significant



comparisons are highlighted in the text, with the results (p-values) of the statistical analyses stated too. Notable insignificant findings, for example those that were not expected, should also be highlighted, and again the appropriate statistical p-values should be shown.

Statistical analysis of more than two "treatments" (i.e. any variant of ANOVA tests) that yield significant results should be followed by *post hoc* analysis, which aims to identify the source of the significant difference. There are several techniques that can be applied here, including the Bonferroni correction³⁹ (originally described by Holm⁴⁰) Tukey's Honestly Significant Difference (HSD),⁴¹ and Scheffe's Test.⁴² It is not the intention of this article to describe these tests in detail but their primary function is to effectively conduct pairwise comparisons of all "treatments" to each other, to assess for significant differences, but by minimising the risk of a Type 1 statistical error (i.e. rejecting the null hypothesis when it is in fact true, thus failing to detect a real effect). The interested reader can find further information from statistics texts such as that by Hinton.⁴³ For example, Wang et al.⁴⁴ applied Tukey's HSD test to determine whether pre- and post-lens tear film thickness, as measured by optical coherence

tomography (OCT), was significantly different with different types of gas permeable and soft contact lenses.

Of importance is for the reader to ensure that the results described fit with the methods previously detailed in the article and that they are relevant to answering the proposed research objective(s).

The Discussion & Conclusions

Having displayed the results of their research, where the author(s) show what they found in their study, they will then go on to discuss what their findings actually mean.⁹ Readers should ensure that the author(s) have interpreted the results of the study correctly, by referring back to the results section of the article and asking themselves if they agree with the statements presented. Highly specialised knowledge is not necessarily required here on the readers' part, with much of the evaluation being based on common sense – do the points made by the author(s) fit logically with what has been presented in the article so far and do they make sense based on existing knowledge? In particular, the author(s) should have offered explanations for the significant findings of the study, with respect to existing knowledge, and other work

Parametric Test	Equivalent Non-Parametric Test	Purpose	Example
Unpaired (or Independent-Samples) T-Test	Mann-Whitney U-Test	To compare the means of two unrelated samples of data drawn from one population	Comparison of the blink rate in patients with dry eye and those with "normal" eyes ³²
Paired (or One-Sample) T-Test	Wilcoxon Matched-pairs (or Signed-Rank) Test	To compare the means of two sets of data, both of which were measured on a single sample	Comparison of the symptoms of patients with dry eye in the morning to in the evening ³³
One-way Analysis of Variance (ANOVA) (F-Test)	Kruskall-Wallis Test	A generalisation of the T-test (or non-parametric equivalent) for a study design where there are more than two "treatment" groups	To determine the effect of different types of refractive error (emmetropia, myopia and hyperopia) on visual fields test thresholds ³⁴
Two-way Analysis of Variance (ANOVA)	Friedman's ANOVA	A generalisation of the T-test (or non-parametric equivalent) for a study design where there are more than two "treatment" groups and there are two variables	To assess corneal oxygen uptake with different hybrid contact lenses and at different corneal locations ³⁵
N/A	Chi-squared (χ^2) Test	To test the null hypothesis that there is no significant difference in the proportions of each variable in a sample	Comparison of demographics (e.g. gender and occupation) of patients selecting contact lenses to those selecting refractive surgery ³⁶
Product Moment Correlation Coefficient (Pearson's r)	Spearman's Rank Correlation Coefficient (σ)	To assess the strength of a relationship or association between two variables	Comparison of how well IOP measured using non-contact tonometry relates to IOP measured using Goldmann applanation tonometry ³⁷
Linear Regression	N/A	To describe the numerical relationship between two variables, to allow one variable to be predicted from the other	Prediction of refractive error from ocular biometry e.g. axial length ³⁸

Table 2

Examples of commonly encountered parametric and non-parametric statistical tests in scientific research (N/A = Not Applicable) (adapted from Greenhalgh⁹)

published in the literature should have been referenced in support. Equally, the authors ought to have explained, or at least suggested possible reasons for, any unexpected significant and/or insignificant findings of the study; for example, this may have been due to an inadequate study design (e.g. an inadequate sample size), unforeseen circumstances, or an unavoidable source of bias.

Of importance is for the author(s) to have discussed the implications of their findings in relation to the impact on clinical practice and the

field in general. This is certainly vital for evidence-based healthcare, so that the uptake by clinicians can be improved and perhaps necessary changes to clinical practice made. Furthermore, this discussion should then lead to the proposition for further research that could be conducted, to confirm the findings and / or to enhance knowledge further. Critical self-analysis of the study is important here, since the author(s) should have evaluated the study design and discussed any flaws that might have impacted on the findings. Of course, if

the flaws were unavoidable, the reader can take some level of satisfaction with the results, whilst avoidable errors will lead readers to question the thoroughness of the study.

Readers should take the opportunity to assess the thoroughness of the discussion by devising their own list of key points from the results section of the article. Based on this, the reader can then determine whether the authors have missed any important findings or if they have failed to acknowledge or explain an important result. Indeed, this can then help the reader

to evaluate the conclusions of the study. Readers should ensure that the authors have drawn their conclusions directly from the results of the study rather than offer mere speculation or opinions that have no foundation on what has been presented in the article; furthermore, the conclusions should have answered the primary (and any secondary) objectives of the study.¹⁴
¹⁵ If this is not the case, there is clear evidence that the author(s) have not successfully completed their research and this will hinder the uptake of their findings into clinical practice.⁹

Some General Pointers

(a) A poor writing style of the author(s) can hinder the reader's understanding of the paper and so it is perhaps advisable for you to look at the results and to interpret them yourself first, and then look at whether your interpretation matches that of the authors.
(b) Whilst reading through an article, always look-up any words or phrases that aren't understood, and write down the definitions for future reference.
(c) Always underline or highlight key phrases, statements or findings in the article. This can be a really useful tool if you need to come back to the article and refresh yourself of the key points with a cursory read at a later date.
(d) Always ask and raise questions as you go along, and write them down. Critiquing the article as you go along will allow you evaluate the later sections based on questions raised in earlier parts; the more questions you raise, the more questionable the research might be.
(e) Always look at the acknowledgements section of the article. It is here that the author(s) will highlight any sources of funding or donations of equipment for the study and readers should look for signs of whether the results were biased towards any supporting bodies. If this is the case, one may question the independence of the research.
(f) Take a look at the date of submission of the article and compare this to the date of acceptance (both are usually printed on the article), as this can give an indication of the quality of the work. A large time gap might suggest that a poor quality manuscript was originally submitted, with many flaws or errors

that had to be corrected as part of the peer review process (although this could also indicate that the reviewers took a long time to review the article!).

Equipped with these basic skills and knowledge, it is hoped that you can now approach the world of scientific articles and journals with more confidence.

About the Author

Dr Navneet Gupta is an Optometrist and Clinical Editor for Optometry Today. He has a PhD in optometry and has written and peer reviewed scientific research articles for journals including Journal of Cataract & Refractive Surgery, Contact Lens and Anterior Eye, and Optometry & Vision Science.

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