Chapter 15
Methods

What key skills are needed when writing the Methods?

This section has several different names including: 'Methods', 'Methods and Materials', 'Experimental', 'Method Description and Validation'. In this chapter, I will always refer to it as Methods.

In most journals the Methods section follows the Literature Review, in others it follows the Conclusions.

The secret of writing this section is to be able to describe the materials you used in your experiments and/or the methods you used to carry out your research, in a way that is sufficiently detailed to enable others in your field to easily follow your method and, if desired, even replicate your work. A key skill is to make sure the descriptions are complete and yet are also as concise as possible, for example by referring to other works in the literature, including your own, that make use of the same or similar methods.

Another key skill is to write extremely clearly, with generally not more than two steps described in one sentence, and in a logical order. This will then enable your readers to easily follow your description.

Researchers generally agree that the Methods the easiest section to write because your methods are likely to be clear in your mind, so it may be a good point for you to begin writing your manuscript.

A. Wallwork, *English for Writing Research Papers*,
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Typical complaints of referees

The methods are not adequately described and are incomplete. How many samples were collected at each sampling? Which sampling method was used and why? Which fraction was analyzed?

No data treatment is shown (statistics, replicates, etc.). Statistical analysis must be reported.

Some of the procedures used were in no way obvious. The authors should justify their rationale for choosing such procedures. At other times the authors repeated a lot of well known published data, when they could have simply used a reference.

15.1 How should I structure the Methods?

The Methods section should answer most of the following questions, obviously depending on your discipline:

- What / Who did I study? What hypotheses was I testing?
- Where did I carry out this study and what characteristics did this location have?
- How did I design my experiment / sampling and what assumptions did I make?
- What variable was I measuring and why?
- How did I handle / house / treat my materials / subjects? What kind of care / precautions were taken?
- What equipment did I use (plus modifications) and where did this equipment come from (vendor source)?
- What protocol did I use for collecting my data?
- How did I analyze the data? Statistical procedures? Mathematical equations? Software?
- What probability did I use to decide significance?
- What references to the literature could I give to save me having to describe something in detail?
- What difficulties did I encounter?
- How does my methodology compare with previously reported methods, and what significant advances does it make?

You should provide enough quantitative information (concentration, temperature, weight, size, length, time, duration etc.) so that other researchers can replicate what you did. Describe everything in a logical order to enable readers to easily follow what you did. This will usually be chronological (but see Sect. 15.9), i.e. the order in which you conducted the phases of your tests. It may also help the reader if you use subheadings to explain the various stages of the procedure, which you can then use again (perhaps with modifications) in the Results.

Your experiments, sampling procedures, selection criteria etc. may have more than one step. It helps your readers if your description of each step follows the same logical order.

Ensure that you cover every step required. Because you are very familiar with your method, you may leave out key information either thinking that it is implicit (and thus not worth mentioning) or simply because you forget.

15.2 How should I begin the Methods?

How you begin will very much depend on your discipline. To help you decide, take a look at the Methods section in papers from your chosen journal, and see how authors start this section.

Typical ways include:

(a) making a general statement about your method

The method described here is simple, rapid, sensitive and ...

(b) referring to another paper

The materials used for isolation and culture *are described* elsewhere [20].

Materials *were obtained* in accordance with Burgess et al.'s method [55].

(c) stating where you obtained your materials from

Bacterial strains ... *were isolated* and kindly supplied by ...

Agorose for gel electrophoresis *was purchased* from Brogdon plc (Altrincham, UK).

(d) explaining how you found your subjects, i.e. begin with the setting

Subjects *were chosen* from a randomly selected sample of ...

Participants *were selected* from patients at the Gynecology Faculty of the University of ...

(e) indicating where (i.e. a geographical region) your investigation was focused

Our empirical investigation focused on Tuscany, a central region of Italy, ...

The study *was carried out* in four boulevards in Athens (Greece) and ...

(f) referring the reader to a figure which shows the experimental set up

To highlight the advantages of the system, Fig. 1 shows the ...

(g) starting directly with the first step in your procedure

Frontal cerebral cortices *were dissected* from ...

Core-cell composite materials *were prepared* by colloidal assembly of ...

15.3 What tense should I use? Should I use the active or passive?

Most Methods sections are written in the PAST SIMPLE using the passive form. Examples of this usage are highlighted in italics in the examples in Sect. 15.2.

The PAST SIMPLE is required because the actions you describe took place in the past (i.e. before you started to write your paper). The PAST SIMPLE also helps to

distinguish what you did from what others have done (which is often described in the PRESENT SIMPLE).

The passive is good style here because the focus is on what was done rather than who did it. Thus you can ignore any expert advice that tells you that the passive should always be avoided. It should be avoided, but only where it is not necessary. In the Methods the passive is both necessary and appropriate.

Greg Anderson, who is the genius behind the biology website at Bates College in Maine, USA, writes the following about the style you should adopt in the Methods section. What he writes clearly not only applies to the field of biology.

> The style in this section should read as if you were verbally describing the conduct of the experiment. You may use the active voice to a certain extent, although this section requires more use of third person, passive constructions than others. Avoid use of the first person in this section. Remember to use the past tense throughout - the work being reported is done, and was performed in the past, not the future. The Methods section *is not* a step-by-step, directive, protocol as you might see in your lab manual.

15.4 How many actions can I refer to in a single sentence?

A frequent problem in the Methods is that the description reads like a manual, where each individual detail or action is described in a single sentence. Given that you are describing a procedure rather than making a complex analysis, it is perfectly acceptable to have two actions in one sentence.

Below is the first paragraph from a medical paper in which the author describes how she selected the participants for her survey on depression. The word 'practice' means an association of medical doctors who offer a service to the public. The 'list size' is the number of patients the practice has.

ORIGINAL VERSION (OV)	REVISED VERSION (RV)
A first postal invitation to participate in the survey was sent to 26 practices in South Yorkshire. A total of five practices indicated their willingness to participate. Multidisciplinary focus groups in four diverse practices were purposively identified. The identification entailed using a maximum variation approach. This approach was based on socio-economic population characteristics and ethnic diversity. These characteristics were taken with reference to census data.	Following a first postal invitation to participate sent to 26 practices in South Yorkshire, five responded positively. Multidisciplinary focus groups in four diverse practices were purposively identified using a maximum variation approach, based on socio-economic population characteristics and ethnic diversity (by reference to census data).

The OV is in correct English and is perfectly acceptable provided that this style is not used continuously throughout the Methods. If it is used continuously, the reader will soon find it tedious, particularly as each sentence begins in the same way (i.e. with a noun).

The technique of the RV is simply to combine two steps into a single sentence, with no extra effort on the reader's part in terms of understanding.

On the other hand, you do not want to have too much information in the same sentence. In the OV below, the reader would find the information much more difficult to assimilate than in the RV, even though the information given is exactly the same.

ORIGINAL VERSION (OV)	REVISED VERSION (RV)
The four practices, which had been previously identified as having list sizes between 4750 and 8200, comprised firstly an inner city practice (hereafter Type 1) with an ethnically diverse population for which the team frequently required translators for primary care consultations, secondly, two urban practices with average levels of socio-economic deprivation (Type 2), and thirdly, a mixed urban/rural practice (Type 3).	The four practices had a list size ranging between 4750 and 8200. They comprised: • an inner city practice with an ethnically diverse population, where the team frequently required translators for primary care consultations • two urban practices with average levels of socio-economic deprivation • a mixed urban /rural practice

In the first three lines of the OV, two pieces of information are included, where the additional information is placed between commas (in italics below):

> The four practices, *which had previously been identified as having list sizes between 4750 and 8200*, comprised firstly an ...

This kind of construction should not be used too often as it separates the subject (*practices*) from the verb (*comprised*) – see Sect. 4.9. Readability is generally increased when the subject and verb are close together, as in the RV. The next lines of the OV then continue with a list of three items. It is much easier if these items are put into three different sentences.

15.5 How can I avoid my Methods appearing like a series of lists?

It is important to be concise in the Methods. But conciseness does not mean writing a series of lists (as in S1). This style may be appropriate on a presentation slide, but should be avoided in a paper. What you write should always sound natural if read aloud. S1 does not sound natural.

S1. Processes which often occur in lipids include: oxidation, hydration, dehydration, decarboxylation, esterification, aromatisation, hydrolysis, hydrogenation and polymerization. Factors that affect the chemistry of these materials include: heat (anthropogenic transformations), humidity, pH, and microbial attacks.

S2 still contains the same *processes* and *factors* as S1, but the way these are introduced sounds more natural - even though it requires more words.

S2. Several processes often occur in lipids, including oxidation, hydration, dehydration, decarboxylation, esterification, aromatisation, hydrolysis, hydrogenation, and polymerization. In addition, the chemistry of these materials can be affected, for example, by heat (anthropogenic transformations), humidity, pH, and microbial attacks.

15.6 Can I use bullets?

The second RV in Sect. 15.4 uses bullets to list the three types of practices. This makes it easier to read and also provides variety in the layout. However, refer to your journal's style guide to check whether bullets are permissible.

You only need to number your bullets if each bullet describes a step that is part of a chronological sequence.

15.7 How can I reduce the word count?

The style of the first RV in Sect. 15.4 is to present more than one action per sentence. This reduces the number of words that are required - the RV is more than 20% shorter than the OV.

Other ways to reduce the word count are:

- assume your readers have basic knowledge of the techniques used in your field, you can thus delete any superfluous information
- cite a reference rather than detailing the procedure again if any of your methods are fully described elsewhere (in one of your papers or someone else's)
- use tables and figures to summarize information
- be concise - see Chap. 5

15.8 How should I designate my study parameters in a way that my readers do not have to constantly refer backwards?

In the second OV in Sect. 15.4 the author has designated the three types of medical practices as Type 1, Type 2 and Type 3. This enables her to save time whenever she has to refer to one of the practices. It saves her time, but not the reader. Later

in the Methods (or even in the Results or Discussion), whenever readers see, for example, Type 1 they will have to refer backwards to remember which practice Type 1 refers to.

Although I generally recommend being concise, in this case conciseness is annoying for readers. It is much easier for readers to read *inner city practice* than *Type 1*.

Another timesaver for the author is to use an invented acronym. So in this case, the author could have written *ICP* for *inner city practice*. But the same problem arises: the reader is forced to remember what *ICP* refers to.

15.9 Should I describe everything in chronological order?

The basic idea is present everything in your experiments, trials, procedures etc. in a way that will make best sense to your reader. The fact you did something before or after something else, may not be relevant for your reader, so in such cases chronology is not important.

However within a sentence or paragraph, readers should feel they are moving forward chronologically.

S1. *The sample, which was filtered and acidified at pH 2, was mixed with X.

S2. *The sample was filtered and acidified at pH 2 and then mixed with X.

S3. The sample was filtered and acidified at pH 2, and then mixed with X.

S4. The sample was filtered and acidified at pH 2. It was then mixed with X, which enabled the resulting solution to stabilize at ...

In S1 the main idea is that the sample was mixed with X, but we seem to be going backwards (to the filtering and acidification) before we go forwards again to the mixing. S2 resolves this problem by removing the *which*-clause and presenting the steps in sequence. However, S2 uses *and* twice, which means the reader may be initially confused with regard to which two items are connected with each other (*filtered* + *acidified*, or *acidified* + *mixed*). This is resolved in S3 by the addition of a comma after *pH 2*. However the clearest version is S4, which simply begins a new sentence.

S1 is an example of a very short sentence that could be rewritten more clearly. Often such sentences are much longer, so the technique given in S4 (rather than S3) is often the best solution.

15.10 What grammatical constructions can I use to justify my aims and choices?

You often need to be able to explain why you made certain choices in the light of what they subsequently enabled you to do.

To introduce your choices you can use the following constructions:

In order to validate the results, we first had to ...

In an attempt to identify the components, it was decided to ...

To provide a way of characterizing the samples, an adaptation of Smith's method [2011] was used.

For the purpose of investigating the patients previous medical history, we ...

Our aim was to get a general picture of ...

This choice was aimed at getting a general picture of ...

The examples highlight that there are many ways (not all mentioned here) to express your aims and intentions. The important thing is to choose the right verb form (see the underlined verbs in the examples): the infinitive (*to test*) or the *-ing* form (*of testing, at testing*).

However, all the examples could be expressed much more simply using the infinitive form alone (e.g. *To validate the results. To identify the components. To characterize the samples*).

Another way to talk about your choices is to use the verb *to choose*. But note the construction:

This equipment was *chosen for* its low cost.

This equipment was *chosen (in order) to* save money.

15.11 What grammatical construction is used with *allow, enable* and *permit*?

There are several verbs in English that mean 'give the capability of' and highlight for your readers what your initial choices subsequently helped you to achieve.

Allow and *enable* are the most commonly used in research papers, and outside computer science they can generally be used interchangeably. Another verb is *to permit*, which is used less frequently as it often has the meaning of an authority

giving someone the permission to do something. All three verbs require the same specific construction. In the examples below I have just used *allow*, but in all these examples from a grammatical point of view *allow* could be replaced with *enable* and *permit*.

GRAMMATICAL CONSTRUCTION	EXAMPLE
allow someone or something to do something	This equipment allowed us to identify X.
allow someone or something to be + past participle	This equipment allowed X to be identified.
allow + noun	This equipment allowed the identification of X.

All three examples mean exactly the same thing. The first is the shortest and most commonly used. It is also the one that gives rise to the most mistakes. This is because *allow, enable* and *permit* require an agent before the infinitive. Hence the use of *us* in the first example is obligatory.

Allow, enable and *permit* involve long constructions but can often be eliminated, generally without any change in meaning. If you find yourself using *allow* and *enable* very frequently, then consider using the alternatives given below. In some cases you may feel that the RV is slightly different in terms of meaning from the OV, in such cases it is best to stick with the OV.

ORIGINAL VERSION (OV)	REVISED VERSION (RV)
Limiting the Xs *allows* the complexity of Y *to be reduced* and permits *the user to control* the deduction process.	Limiting the Xs *reduces* the complexity of Y, and *facilitates control* of the deduction process.
The analysis *allowed the characterization of pine resin* as the main organic constituents in the sample to be achieved.	The analysis *showed that pine resin* was the main organic constituent in the sample.
This model *permits the analysis* of X.	This model *can analyze* X.
	With this model *we can analyze* X.
	With this model, X can be determined
The use of these substrates *enabled us to highlight* the presence of several nucleases.	The use of these substrates:
	highlighted the presence of ...
	meant that we were able to highlight the presence of ...
	offered a means *to highlight* the presence of ...

Note that in the RVs, the verb *let*, which means the same as *allow, enable* and *permit*, has not been used because in most journals it is considered too informal.

15.12 How can I indicate the consequences of my choices and actions?

In Sect. 15.10 we saw how (i) to indicate the rationale behind your choices, then in 15.11 (ii) what this choice enabled you to do. Now we will look at how to describe the consequences of (i) + (ii). Here are some examples:

S1. An evaluation of this initial data demonstrated that X = Y,
thus giving an insight into the function of Z.
thereby providing a basis for investigating the function of Z.

S2. An evaluation of this initial data demonstrated that X = Y.
Consequently the next step was to investigate the function of Z.
The next step was *thus / therefore / consequently* to investigate ...

The examples above give two alternative endings.

In S1 the sentence is in two parts divided by a comma after *Y*. Note how *thus* and *thereby* require the *-ing* form after them. The *-ing* form alone, without *thus* and *thereby* could be ambiguous (Sect. 6.5).

In S2 the first sentence ends with Y. The first word in the next sentence is *consequently*. It would be possible to put *thus* and *therefore* (but not *thereby*) at the beginning of the sentence too but their most natural position is after the verb *to be* (Sect. 2.12). Other alternative words are *hence*, which is most generally used in mathematics, and *so*, which is generally considered too informal for research papers.

15.13 How should I use the definite and indefinite articles in the Methods?

Below is the first part of the entire experimental section of a paper entitled *Growth of Diamond Films from Tequila* by Mexican researchers Javier Morales et al. Their English reflects the typical use of English in scientific papers, by native and non-native authors, but which EFL and EAP trainers may find strange.

> Small pieces of *a Si* (100) wafer and commercial stainless steel (type 304) were used as substrates, fixed to the holder through silver paste. *Temperature* was controlled at 850°C through *an automatic* PID temperature control (Eurotherm). *Reactor pressure* varied from 4.76 to 4.99 Torr due to the injection processes and to the flash evaporation phenomena. The carrier and reaction gases flux were fixed at 0.8 and 0.1 l/min, respectively. “Tequila blanco” (white tequila) Orendain brand, a clear, un-aged liquor distilled from the juice of blue agave (Agave Tequilana) plant [9], was used *as precursor*.

In italics I have highlighted some issues with articles (*a/an, the*). In the first line *Si* stands for silicon. If you read the sentence you would probably read it as: *a silicon wafer* and not *an Si wafer*. *Si* is not an acronym - you would say, for example, *an SOS*, because each letter in SOS stands for a separate word. In SOS the S is pronounced ESS and therefore requires *an* (see Sect. 11.15) because of the initial vowel sound (as in *an automatic* in the third line).

In Morales' paper, like in most scientific papers, the use of *a* and *the* goes against the normal rule of a singular countable noun requiring a preceding article (see Sects. 6.6 and 11.14). Morales uses, like many native speakers, *temperature* and *reactor pressure* without a preceding *the*. However, other authors opt to use *the* in exactly the same situation. Clearly in such contexts both forms are permissible.

Likewise, Morales writes *as precursor*, which in general English would have to be *as a precursor*, which is what some other authors in the literature use. So again, in these cases at least, both forms seem to be possible, though the solution with *a* is twice as common.

15.14 Should I write numbers as digits (e.g. 5, 7) or as words (e.g. five, seven)?

Below is the second and final part of Morales' experimental, which highlights some useful points with regard to numbers.

> This tequila, 80 proof and with C-H-O atomic relationships of 0.37 C, 0.84 H and 0.29 O (Figure 1), was injected at a frequency of 2 pulses per second (500 ms) with an opening time of 4 ms. A total of 21768 pulses were applied in each experiment and a micro dose of 6.26×10^{-3} ml was injected per pulse (Table 1). Temperatures in the evaporation zone and along the vapor transport line were fixed at 280°C. The deposit was studied through a Dilor micro-Raman spectrometer with a 20 mW, 632 nm He-Ne laser equipped with a confocal microscope and a JEOL Low-Vacuum Scanning Electron Microscope (JSM-6060LV), operating at 15 kV, secondary electrons, spot 50 and WD 11 mm.

The use of numbers varies from journal to journal and paper to paper. In Morales' paper all the numbers are written as digits rather than words (e.g. *2 pulses* rather than *two pulses*).

Other journals recommend using words for numbers from one to ten, and then digits. However this rule does not apply when the number precedes an abbreviation for a measurement (e.g. *9 mm*, not *nine millimeters*).

Note also that abbreviations for measurements do not have an *s* when they are plural (e.g. *9 mm*, not *9 mms*).

Another rule of style prohibits beginning a sentence with a number in digits. For this reason Morales correctly writes

... opening time of 4 ms. A total of 21768 pulses were applied ...

rather than

... opening time of 4 ms. 21768 pulses were applied ...

In fact, you can see clearly from these two examples why the rule exists. It exists to help readers see the numbers more clearly. Alternatively, you can begin a sentence with a written number:

Twenty thousand pulses were applied …

Clearly, if you begin a sentence with a number in words, the number has to be a short number. Writing the following would be ridiculous:

Twenty one thousand seven hundred and sixty eight pulses were applied …

The last sentence of Morales' experimental contains nine pieces of information, but it is not difficult to follow, and it would be strange to break the sentence down into smaller parts.

15.15 How can I avoid ambiguity?

Morales' experimental (see Sects. 15.4 and 15.13) is easy to read and follow. One reason for this is that it contains no ambiguity. There is no phrase that forces the reader to stop and interpret the meaning.

Unfortunately, not all Methods are written in this way.

In Robert Day's informative and very amusing book *How to Write and Publish a Scientific Paper*, several real examples of ambiguous sentences from Methods sections are given. Here are two of them:

S1. *Employing a straight platinum wire rabbit, sheep and human blood agar plates were inoculated ...

S2. *Having completed the study, the bacteria were of no further interest.

In S1 it seems that the rabbits were made of platinum wire, and in S2 it seems that the bacteria were responsible for completing the study. You may think that the real interpretations are very obvious, but the fact that Robert Day mentions them means that some referees and readers will also find them amusing and/or aggravating. One solution is to improve the punctuation as in S3, where a comma has been added after *wire*.

S3. Employing a straight platinum wire, rabbit, sheep and human blood agar plates were inoculated with ...

In S3 a comma has been added after *wire*. But the sentence is still not immediately clear because the use of a series of commas initially makes it seem like a list of things that were employed. S4–S6 are much clearer.

S4. Rabbit, sheep and human blood agar plates were inoculated with … by employing a straight platinum wire.

S5. Employing a straight platinum wire, we inoculated rabbit, sheep and human blood agar plates with …

S6. Rabbit, sheep and human blood agar plates were inoculated with ... This was carried out using a straight platinum wire.

S2 could be rewritten as:

S7. Once the study had been completed, the bacteria were of no further interest.

For more on such problems of ambiguity, see Chap. 6.

15.16 What other points should I include in the Methods? How should I end the Methods?

Not all Methods sections are as short as the one by Morales et al. (Sects. 15.13 and 15.14).

In some papers the methods are the main contribution of the paper. In such cases, subsections with subheadings (e.g. *sampling procedure, experimental set up, testing the model*) may help readers to understand the various stages or various components.

Your first subsection may be a general overview of the methods chosen, how they relate to the literature and why you chose them.

Then in each subsequent subsection you:

1. preview the part of the procedure / method you are talking about
2. detail what was done and justify your choices
3. point out any precautions taken (this also helps you gain credibility as a researcher who carries out his / her work accurately and thoroughly)
4. discuss any limitations in your method or problems you encountered
5. highlight the benefits of your methods (perhaps in comparison to other authors' approaches)

If your Methods section is short and does not require any subsections, then you could end it with one or more of points 3–5 above. If it is long, then you could end with some conclusions regarding the limitations and benefits (points 4 and 5) of your overall methodology.

However, many authors follow Morales' approach - essential, concise and no conclusions. As usual, the best solution is to analyze the Methods section in various papers that have been published in your chosen journal.

15.17 Summary: How can I assess the quality of my Methods section?

To make a self-assessment of your Methods section, you can ask yourself the following questions.

- Have I really described my Methods in a way that is easy for readers to follow and which would enable them to replicate my work? Have I ensured that I have covered every step? Is my structure clear and complete?
- Have I been as concise as possible? Have I used references to previous works rather than repeating descriptions that readers could easily find elsewhere?
- Do the individual sentences in each paragraph contain too many, too few, or just the right manageable number of steps? Have I ensured that my sentences don't sound like lists?
- Have I thought about the way readers prefer to receive information? (no ambiguity, no back referencing, everything in chronological order, headings, bullets)?
- Have I checked my grammar (infinitive, gerund, *allow, thus* etc.) with regard to how I outline how and why I made certain choices?
- Have I checked my journal's guidelines on how to use numbers?
- Have I used tenses correctly? PAST SIMPLE (in the passive form to describe what I did), PRESENT SIMPLE (descriptions of established scientific fact)