WRITING A SCIENTIFIC PAPER – BIOL 320 Fall 2016
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The Goal of Scientific Writing

Scientific papers come in three main forms: papers that are intended to be published in journals, which are written either to (1) disseminate the results of original research (a "research" paper) or (2) to synthesize and review a group of research papers published by many different researchers that all relate to a specific topic (a "review" paper); or (3) grant proposals, which are submitted to funding agencies and propose new research to be performed (*if* the funding agency gives the investigator money!). In all three cases a premium is placed on writing that is *clear* and *concise*. The accepted style of scientific writing is highly stereotyped and well defined, but scientific writing is still challenging because it is so different from writing essays in the humanities. This guide is geared toward the sections in a typical research paper, but will be useful for writing proposals as well.

General Scientific Style

Papers should be double-spaced throughout using 12-point font (Times New Roman). Pages should be numbered, in case they get separated. Leave 1" margins on each side of the page to leave room for comments by people reviewing your work. Although you may see some variation, the standard research paper has, in order, a *Title*, *Abstract*, *Introduction*, *Methods*, *Results*, *Discussion*, and *References* sections; grant proposals often have different sections, but are written in similar style and include many of the same components (i.e. an introduction, proposed methods, presentation of preliminary data, etc.). The components of each section are described below, but the best way to learn how to write in the sciences is to read scientific articles.

Very general statements of background information believed to be universally true are usually presented in the present tense (e.g. "the hippocampus and associated neural structures are critical for memory formation . . . "). *References* to particular studies that others have performed, however, are usually referred to in the past tense because they were performed in the past (e.g. "Eichenbaum et al. (2011) recently showed that the hippocampus . . . "). Anything referring to your particular experiment (e.g. *Methods* and *Results*) should definitely be written in the past tense, because your paper describes experiments that you recently completed in the past (e.g. "flies were placed in the experimental arena and allowed to explore freely for 5 min . . . ").

While passive voice has historically been and continues to be used in scientific writing (e.g. "the ability of flies to discriminate between objects in familiar and novel locations under different temperature regimes was quantified using a preference score calculated as. . . "), it is now considered acceptable to use active voice[1] ("I" and "we"), especially in the *Methods* section (e.g. "we quantified the ability of flies to discriminate between objects in familiar and novel locations using a preference score calculated as . . . ". However, the style of scientific papers is still very formal so avoid using "you", rhetorical questions, or contractions.

Quotes are not acceptable in scientific writing. Paraphrase any ideas that are not your own and provide proper citations (see **References**).

[1] This is a fairly recent change in science writing – passive voice used to be the rule, and using first person was considered informal and inappropriate. In older articles, you will see passive voice used almost exclusively.

Organism names should be provided in Latin and should be italicized. Latin names are given as *Genus species*, with the genus name capitalized and the species name as lowercase (e.g. *Drosophila melanogaster*). Write the full name of the organism the first time you use it in the title, abstract, and body of text. Once you have use the full name once in the body of the paper, you may use the abbreviated name: *G. species* (e.g. *D. melanogaster*).

Title

In about twenty words or less, describe the topic studied and the model system or organism used. Your title should give clues about the subject studied and an idea about the experimentation used. It can be in sentence structure, but usually it is not.

Abstract

This section is one paragraph in length, generally about 200–300 words. There should be no references in your abstract. It is a summary of your entire paper and should have a couple of sentences devoted to roughly summarizing each section:

- The reason for studying the topic or what the purpose of the experiment was (*Introduction*);
- Briefly how you studied this topic (*Methods*);
- What major results you found from your experiment (*Results*); and
- How your results contribute to the greater scientific understanding, why your results are important, or how your results can be applied to other scientific questions (*Discussion*).

Introduction

The *Introduction* serves to:

- Present sufficient background information to understand the point of doing the experiment;
- Provide scientific context and show how the experiment relates to what others have previously done in the field;
- Demonstrate that what you have done is something novel and interesting; and
- Present background information that supports your hypotheses.

I recommend that you write your *Introduction* starting with general background information and then go to specific information. You should end the introduction with a statement about what you did and why you did it (your research goals or specific hypotheses). Your goals and hypotheses should be based on background information and logical inference about what outcomes should be expected, not upon data collected during the experiment. Therefore, your data presented in the *Results* section may help to support OR refute your hypotheses.

Good scientific writing builds a logical case for why the particular experiment being described is interesting and relevant. The backbone of this logical case is the background information you provide in your *Introduction*, which must come from peer-reviewed scientific literature (see **References**). ALL ideas from the literature must be cited so the reader knows where those ideas originate from and can read those papers on their own, if desired (see **References**). The only ideas that should not be cited are those that are entirely your own. All cited material should be paraphrased (not directly quoted); it should be in your own words and you should demonstrate its relatedness to your experiment. It is almost impossible to have too many citations in a scientific paper, but *not citing enough (by stating ideas that are not your own* *without a citation) constitutes plagiarism, which I take very seriously in this class.* Reading published journal articles is the best way to understanding how scientists expect authors to report ideas that are not their own.

Methods

The purpose of the *Methods* section of a scientific paper is to convey the exact method(s) by which the study was carried out. While seemingly straightforward, the *Methods* section can still be very difficult to write well. As the author, your most challenging task is to strike an appropriate balance between level of detail and readability: A good *Methods* section will *omit the basic details that any scientist in the field would know* (such as how to use a micropipette properly, or how to load a gel) while *still providing enough description, observations, and details about the particulars of your experiment* (such as the suppliers, amounts, and incubation times of antibodies used during histological staining) *to allow the successful repetition of your study by someone else, using only your text as a guide.*

Content and organization of the *Methods*

It is important that the *Methods* section be complete with all the details that another scientist would require in order to reproduce the experiment. These include:

- Exact measurements of important quantities. This includes all the reagents used, their amounts, and the timing and order of different steps. You would not list quantities that are not required to replicate the study, such as the number of times you changed pipet tips, the volume of distilled water you used to clean out your glassware, etc.

- Clear, concise descriptions of the techniques employed.

- Exact numbers of samples.

- The commercial suppliers of key or unusual reagents or supplies. For items that are critical to a particular technique, such the gas analyzer used to measure metabolic rate, another experimenter trying to replicate your methods might want to purchase the exact same product, so you should indicate the supplier (and, if known, the item number) of such items. You would not do this for common reagents and supplies that are presumably interchangeable, such as standard buffer solutions, pipet tips, etc.

- Measurement criteria. How did you measure the outcome of your study? What criteria did you use to discriminate a "positive" from a "negative" result, or to place observations into specific categories?

- Which statistical tests were used to evaluate the data.

Format and style of the *Methods*

The *Methods* section should be written in standard paragraph form. It is always written in the past tense (you already performed everything that you are describing) and, when it makes sense, in active voice (i.e. "we did x" instead of "x was done"). In addition to prose, the Method section can occasionally contain diagrams or illustrations of things like custom or unusual equipment, or flow charts of extremely complicated multi-part procedures. *It never contains charts or graphs of the gathered data* – these are presented in the *Results* section!

Many journals will break down the *Methods* into subsections, usually corresponding to the different major experimental techniques that were used in a multi-part study (for example, “Gel electrophoresis”, “Immunocytochemistry”, “RasV12 transfection”, “Fluorescence microscopy and image analysis”, etc.). Furthermore, when complicated statistical analyses are performed on the data from a study, the last subsection of the *Methods* is often devoted to describing them. Using these sections can make the *Methods* section significantly easier to read and significantly less cluttered.

Methods subsection headings should be italicized. You are not limited to a specific number of subsections, but they should be consistent with the number of parts of the experiment you performed.

Length and depth of the *Methods*

There is no maximum length for the *Methods* section. That said, instructions should be concise and to the point. Do not add unnecessary flourishes to make it sound better. Equally important is the need to be complete - don’t omit an important detail in the name of brevity. The key skill when writing a *Methods* section is to *balance detail and readability* – making the text as short and to the point as possible, while retaining all the information needed to replicate the study.

Results

The *Results* section, like the *Methods* section, has a very narrow purpose – to clearly convey the findings of the study, both in prose and as informative figures and tables. Perhaps the biggest pitfall of writing a *Results* section is the temptation to interpret the findings of the study. However, this is the function of the *Discussion* section of a scientific paper, not the *Results*. The *Results* section should read as a clear, straightforward, objective reporting of the findings of the study.

Content and organization of the *Results*

The text of the *Results* section should simply report the results of your experiment and your statistical analyses in straightforward, concise terms. When you describe results that are summarized in a figure or table, you should cite that figure or table in parentheses. You should not discuss why these results and analyses are interesting or important, or how they are related to the overall context of your experiment – these passages belong in the *Discussion* section.

The *Results* section will include a thorough description of the outcome(s) of the study performed. Numerical results (for example, the average resting heart rate vs. the average post-exercise heart rate) are often best presented in tables or graphs (but rarely both for the same results) that summarize a great deal of information in a way that clearly and quickly conveys their import to the reader. In contrast, qualitative results (for example, descriptions of how specific tissues look under a microscope) are often best presented verbally, perhaps with reference to figures including pictures or micrographs of the phenomenon being described. For experiments of limited scope and length, a *Results* section might be extremely brief; even as small as a single paragraph (there must always be one) of text with a single associated figure. Conversely, for studies with long, multi-part, complicated methodologies, the *Results* section may be long, contain many figures, and be subdivided into subsections to improve readability.

Reporting Statistical Results

I do not expect you to calculate statistical tests by hand in this class, but you should understand how to report statistical results and how to interpret *p* values. In the scientific literature, authors are expected to clearly report their statistical results. At a minimum, a statistical test should be accompanied by the test statistic and its associated degrees of freedom and p value (if these terms are foreign to you, refer to the *Basic statistics guide* posted on Moodle). The test results are usually reported in a parenthetical after a verbal description of the results, with the degrees of freedom given as a subscript to the test statistic. For example, for a hypothetical experiment where visual acuity was compared between men and women:

> The number of correct responses on the visual acuity test did not significantly differ between men and women ($t_{38} = 1.85$, $p = 0.07$).

Authors often also identify the type of test performed, particularly the first time it occurs in a paper. For example:

> The number of correct responses on the visual acuity test did not significantly differ between men and women (t test: $t_{38} = 1.85$, $p = 0.07$).

A more complete results section includes descriptive statistics, such as means (abbreviated x) and measurements of variability, such as standard deviation (abbreviated SD), standard error (often called standard error of the mean and abbreviated as SE, SEM, s. e. m., etc.), or 95% confidence intervals (95% CIs) in addition to the results of statistical tests. For example:

> Men averaged fewer correct responses (x ± s. e. m. = 75.0 ± 1.96) than women (80.0 ± 1.86) on the visual acuity test. However, this difference was not statistically significant (t test: $t_{38} = 1.85$, $p = 0.07$).

Significant results ($p < 0.05$) are reported in similar fashion. If a p value is very low, indicating extreme confidence that the null hypothesis is incorrect, the exact value is not reported. This generally occurs when p is less than 0.0001. For example:

> Male subjects averaged significantly fewer correct responses on the visual acuity test than female subjects (t test: $t_{38} = 5.00$, $p < 0.0001$).

Format and style of the *Results*

Like the *Methods*, the *Results* section will contain prose written in paragraph form, but unlike the *Methods*, the *Results* section will almost always contain figures and/or tables, and often more than one. *A Results section that consists solely of tables and figures is not acceptable, however; the section must always contain text that summarizes all of the results.* Ideally, a person reading your paper should be able to understand your findings without ever looking at a table or graph. However, it is fair to say that the tables and figures are the centerpiece of the *Results* section, and should be carefully constructed and presented to maximize readability and information content. All graphs and figures must be properly formatted, numbered, and referenced in the text (See section on Preparing tables and figures below). If your experiment contains multiple (more than

2) central results, then you may find it useful to break your *Results* into smaller subsections, as with the *Methods*.

Graphs, charts, and diagrams are called "Figures" and tables are called "Tables." Captions are placed below a figure and above a table using the format:

Figure {#}. {Caption}
or
Table {#}. {Caption}

Figures and Tables are numbered separately (e.g. there can be a "Figure 1" and a "Table 1" in the same paper) in the order that they are referenced in the text. Captions should be short (up to a few sentences), with an initial statement that gives an overview of the figure or table and what it shows, followed by a detailed description and a legend that explains the meaning of any abbreviations or symbols. A good figure/table and caption should give the reader enough information to interpret it on its own, even if it was removed from the paper.

Raw data should never be presented except in very rare circumstances. This means tables should include summary statistics (means, sample sizes, standard deviations, etc.) and/or statistical details (test statistics, p values, etc.), but should not be lists of raw observations. For figures, comparisons between experimental treatments (e.g. heart rate before and during a simulated dive) are often shown as bar graphs, with the height of the bar indicating the mean for each treatment for a given measurement and error bars that correspond to measures of variation for each mean (e.g. standard deviation, standard error, or 95% confidence intervals). Make sure the x- and y-axes of each figure are clearly labeled with the units, if any, of the measurement being shown. Refer to the *graphing guides* posted on Moodle for a more complete walkthrough of using Excel to produce quality figures.

Length and depth of the *Results*

As with the *Methods*, there is no standard length for a *Results* section. The text component of a *Results* section is typically as brief and concise as possible, and it is often shorter than the *Introduction*, *Methods*, or *Discussion*. However, the *Results* section also generally includes all of the figures and tables in the paper; thus, it takes just as much, if not more, time and effort to write a good *Results* section as any of the other sections.

Discussion

This is where you tie it all together and end with a bang. You should:

- Restate the purpose (objectives) of the experiment;
- State whether your results agreed with your hypotheses or not, referring to your figures and tables again, and briefly restating the results. Remember, an experiment can only support or not support a hypothesis – you never "prove" a hypothesis;
- Talk about whether your results agree with what others have found. Thus there will be references in your *Discussion* as well as your *Introduction*;
- Talk about any problems encountered during the experiment, how these problems may have affected the experiment, and how you would fix these problems in future studies;
- Discuss any future experiments that should be done to extend or follow up on the results of your study, or to address any questions that still remain unanswered after your study; and

- Close with a discussion about the importance of your experiment to the greater scientific knowledge, how you have contributed to the understanding of the topic, and/or how your results can be applied to other scientific problems.

References
Different academic journals have their own (generally arbitrary) formatting styles for references. In this class, we will use the style of a journal that publishes physiological research: the *Journal of Comparative Physiology A*[2]. In this journal – as is true for most scientific journals – encyclopedias, newspapers, websites (including Wikipedia), textbooks (including our textbook) or any other non-academic sources are not acceptable for citation. Any ideas that did not originate from you must be cited; failure to do so constitutes academic dishonesty (plagiarism). Furthermore direct quotes are not acceptable, even if cited. While this would not constitute academic dishonesty, it is considered inappropriate scientific style – you should always paraphrase and cite your sources.

There are two components to referencing someone else's ideas: in the text and in the *References* section. As you write your paper, cite any ideas you got from outside literature sources in the text. Then, in the *References* section, put the references for these sources in alphabetical order according to the first author's last name.

<u>In-text Citations</u>
There are two ways to cite information in the text of your paper. The author(s) can be used as the subject of the sentence, with the publication date in parentheses, as in the following example:

> Pritz (2011) argued that similarities among the brains of mammals and reptiles in the circuits connecting the cerebellum and dorsal column nucleus suggest these circuits evolved in the ancestors of modern amniotes.

Or, the full citation (author[s] date) can appear in parentheses after you paraphrase the idea, as in the following example:

> Improper GABA receptor functioning has been proposed as an important causal factor leading to the development of epilepsy (Gonzaléz and Brooks-Kayal 2011).

When there are three or more authors, the in-text citation is shortened to the first author's last name and "et al.". The et al. is short for *et alia* which means "and others" in Latin. For example:

> Lecanu et al. (2011) recently showed that the natural compound solasodine induces neurogenesis from existing neuronal precursor cells, providing a novel avenue of research into potential therapies for human neurodegenerative diseases.

Or:

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[2] The full title is the *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology*. The *Journal of Comparative Physiology B* publishes articles that deal more will cellular and molecular physiology.

In guinea pigs, spontaneous neuronal firing rates in the ventral cochlear nucleus increase after physical trauma to the cochlea (Vogler et al. 2011).

When citing multiple references in one parenthetical, list citations in chronological, then alphabetical order, and separate the citations with semicolons.

Several studies have shown that neuroanatomical development in honey bee workers is influenced both by their age and prior task experience (Withers et al. 1993; Durst et al. 1994; Sigg et al. 1997; Farris et al. 2001).

Articles by the same authors can be listed by year without repeating the authors each time.

Differences in neuroanatomy, neurochemistry, and brain gene expression have all been suggested to produce behavioral variation among workers in the ant genus *Pheidole* (Seid et al. 2005, 2008; Seid and Traniello 2005; Lucas and Sokolowski 2009).

If there are ambiguous citations with the same authors and year, differentiate them using lowercase letters:

Neural network simulations have suggested that spike-timing-dependent-plasticity (STDP) could be important in generating long-term memory (Gilson et al. 2009a,b).

References Section Citations

References should be listed in alphabetical order by the first author's last name, not the order in which they appeared in the main text. Unlike in the text, all authors should be listed in the *References* section unless there are more than 10, in which case et al. may be used.

• For journal articles:

{Authors} ({Year}) {Article Title}. {Abbrev Journal Title} {Volume}:{Pages}

Durst C, Eichmuller S, Menzel R (1994) Development and experience lead to increased volume of subcompartments of the honeybee mushroom body. Behav Neural Biol 62:259-263

Gilson M, Burkitt AN, Grayden DB, Thomas DA, van Hemmen JL (2009a) Emergence of network structure due to spike-timing-dependent plasticity in recurrent neuronal networks I: input selectivity-strengthening correlated input pathways. Biol Cybernet 101:81–102

Gilson M, Burkitt AN, Grayden DB, Thomas DA, van Hemmen JL (2009b) Emergence of network structure due to spike-timing-dependent plasticity in recurrent neuronal networks II: input selectivity-symmetry breaking. Biol Cybernet 101:103–114

Lecanu et al. (2011) The naturally occuring steroid solasodine induces neurogenesis in vitro and in vivo. Neuroscience 183:251-264

• For academic books:

{Authors} ({Year}) {Book Title}. {Publisher}, {City}

Hölldobler B, Wilson EO (1990) The ants. Harvard University Press, Cambridge

• For separately authored chapters in an academic book:

{Authors} ({Year}) {Chapter Title}. In {Editors} (eds) {Book Title}. {Publisher}, {City}, pp{Pages}

Neckameyer WS, Leal SM (2009) Biogenic amines as circulating hormones in insects. In: Donald WP, Arthur PA, Susan EF, Anne ME, Robert TR (eds) Hormones, Brain and Behavior. Academic Press, San Diego, pp 967–1002

• For online-only journals:

An online-only journal is a website that publishes peer-reviewed scientific articles on a weekly or monthly basis just like normal journals, but does not publish a printed hard copy. The most prominent such journals you are likely to encounter are the Public Library of Science (PLoS) publications *PLoS ONE* and *PLoS Biology*. Both are peer-reviewed, open-access, online-only journals that publish physiology articles. An online-only journal is not the same as a print journal that also has an online version (which almost all do). Print journals (even if the articles can be found online) should be cited as above. Citations to online-only articles should appear in the *References* section as follows:

{Authors} ({Year}) {Article Title}. {Journal Title} {Volume}:{Identifier Number}

Gospic K, Mohlin E, Fransson P, Petrovic P, Johannesson M, Ingvar M (2011) Limbic justice – amygdala involvement in immediate rejection in the Ultimatum Game. PLoS Biology 9:e1001054

Finding References

You can find references using online databases that allow for easy keyword searches of peer-reviewed scientific articles – there are several of these (e.g. Web of Science and PubMed), but Google Scholar (http://scholar.google.com) has improved so much over the last few years that it is now my suggested option for finding references online (and it's free!). You must be connected to the internet via the Hendrix network to get the most out of Google Scholar (it will automatically give you links to the full text of articles when Hendrix has a subscription to the journal). You can either be physically on campus or connect to the Hendrix network remotely, for example by VPN (https://www.hendrix.edu/HelpDesk/article.aspx?id=28388).