Writing a paper is like writing a proof

Lena Ting, June 19, 2023

• **Start early.** If you know what you're trying to do, you can outline or even write a "fantasy paper" before you even start collecting data or doing analyses. If you don't know what you're trying to do, you should outline a "fantasy paper" to see if you can figure out what you question you should be answering and how. Fantasy papers should have a nice title, rationale, and sketches of figures that tell the story.

• **Writing and analyses go hand in hand, don't do them serially.** Understand that your paper will change as you analyze results and that your analysis will changes as you write your paper, so don't wait to write you paper until you've "finished" your results. If you wait 'til you "finished" your results, you'll be sorely disappointed that there are missing analyses necessary to tell a logical story with all the proper control analyses.

• **Write a short (200wd) abstract to sharpen your thoughts.** A very brief abstract helps you organize a paper and find the salient point that need to be addressed in your manuscript. I find that a good time to do this is after you wrote a stream of consciousness first draft and need to do some sharpening, reorganizing, and cutting. Also, this is why conference abstracts are a good way to help focus a project. Note that doing a 200-word abstract is VERY HARD. Keep trying. You want to be sufficiently high-level so that the importance is well-stated, and sufficiently low-level that is it still tied to your actual results, and not a generic abstract that might hold for several papers.

• **An introduction's purpose is only to motivate the particulars of what you will do in the paper.** There is a tendency to write a "background" that does not inform HOW the study was done, nor the specific metrics used to evaluate the study against the stated goal or hypothesis. Four to six introduction paragraphs is more than sufficient:
> • The first talks about the major question, goal, or hypothesis.
> • The last starts with exactly what you did. Sometimes it is useful to write this paragraph first as an outline for the introduction. Something like "Here we tested the hypothesis that ….. We used XX as a paradigm for YY… We evaluated ZZ outcomes… We predicted that ZZ would be different in XX. …
> • The middle paragraphs make it such that there is nothing surprising in the last paragraph. You want to introduction paragraphs so that they end with a sentence about the choices you made in you study. i.e., Therefore, we chose to use XX as a paradigm for YY. OR Therefore, our experiments manipulated ZZ while measuring WW. These sentences are only here to ensure that your paragraph makes the reader ideate your exact experiment while reading the introduction. Once you have completed your introduction, then you can move those sentences to the last paragraph. The reader will then be in a mind-meld with you while reading the last paragraph, and prepared to understand why the particular results you present tell the story that you want to tell.

• **Writing a paper is like writing a proof.** This brings us to the Krakauer method of writing a paper, which sets up a very formulaic structure for your whole paper where the order or presentation is pretty much identical in the introduction, methods, results, and discussion. Told me directly by John Krakauer.

I find this approach to be helpful to engineers to demystify the writing process. This is not creative writing–we don't care about transitions sentences, or sounding eloquent. Put away any distracting thoughts or prior traumas from English class. You can think about writing a paper like commenting code

(which you better be doing). Here is the code to do X in order to achieve Y. Here is the code block do X. Here are the results from computation X. Here is how results from X are used for Y.

The process starts with a set of figures you wish to present. For each figure you write ONE sentence encapsulating:
1. What we asked
2. What we did
3. What we found
4. What it means.

My prior failing in teaching this method is in its relationships to writing the paper. These sentences, when written well, serve as a good initial attempt at the first sentence of each paragraph for the
1. Introduction
2. Methods
3. Results
4. Discussion

This keeps all the text focused on motivating and explaining the results, with perhaps an introductory paragraph at the beginning of the paper.

Filling out the following table with coherent full sentences literally gives you the topic sentences for paragraph in your paper. Write them out fully to be the most effective, not just writing out notes or shorthand.

	Intro Section **What we asked**	Methods Section **What we did**	Results Section **What we found**	Discussion Section **What it means**
	Topic sentence for Intro para 1	First methods paragraph: Overview, study population	First results paragraph: statement of experimental success	Summary of discussion points (and not results), can be an outline for the section
Figure 1	Topic sentence for Intro para 2	Topic sentence for Methods para 2	Topic sentence for Results para 2	Topic sentence for discussion para 2
Figure 2	Topic sentence for Intro para 3	Topic sentence for Methods para 3	Topic sentence for Results para 3	Topic sentence for discussion para 3
Figure 3	Topic sentence for Intro para 4	Topic sentence for Methods para 4	Topic sentence for Results para 4	Topic sentence for discussion para 4
Figure N		…	…	…
	Topic sentence for final intro paragraph	Topic sentence for Methods para 5 – statistical methods		Topic sentence for implications and impact

• **Once you have your paragraph topics make sure you stay on topic.** The first sentence of the paragraph should tell the whole story, and the body of the paragraph should provide supporting material for that topic. Think of the first sentence as the title, or the thesis statement you wish to prove, just as in a mathematical proof. Often these statements will end up at the end of a paragraph you write during a stream of consciousness dump that helps you understand what arguments you want to make. I call this up-side down writing. Once you find these gems, reformulate them as the take-home messages that you put at the beginning of the paragraph. Rhen the next sentence can start from the original paragraph beginning to build the argument. A great skill to learn is to skim through your written first draft text and circle the most salient sentences that encapsulate the message in each paragraph then move it to the beginning and edit your paragraph to suit. I call this "upside-down" writing. Once you are a ninja, you can start to write these sentences when you begin.

> • For example: in the first draft of this paragraph the main point is in the last sentence:
>
>> Due to experimental limitations, three metrics A, B, and C cannot always be directly compared. However, there are certain experiments in which A and B can be compared and shown to be equivalent. Computational methods further enable B and C to be compared. Through a combination of experimental and computational approaches, and with appropriate control, it is possible to conclude that A and C are equivalent. *Therefore, the transitive property is an important principle for showing equivalence of two metrics that cannot be directly compared experimentally or computationally.*
>
> • Simply moving the last sentence to the beginning gives the reader some context and a target to evaluate whether each subsequent sentence is supporting the take-home message:
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>> *The transitive property is an important principle for showing equivalence of two metrics that cannot be directly compared experimentally or computationally.* Due to experimental limitations, three metrics A, B, and C cannot always be directly compared. However, there are certain experiments in which A and B can be compared and shown to be equivalent. Computational methods further enable B and C to be compared. Through a combination of experimental and computational approaches, and with appropriate control, it is possible to conclude that A and C are equivalent.
>
> • Think of this sentence as the title of your power point slide, or the main thing you want readers to remember. This makes the text easier to read so that the reader can look at the first sentence of each paragraph and skip it if they agree with the thesis. This makes it especially important that you do not add additional ideas into the paragraph. If there are extra ideas in the paragraph, you either need to change the topic sentence, or make a new paragraph.

• **Methods and results deserve English-language topic sentences too**. A lot of jargon can come into methods and results section. The first sentence of each section should explain what you're doing without all that. For **methods**, it is good to state we collected biomechanics data as the first sentence. Then you can go into all the various things you collected and at what sampling frequency. Similarly, each **results** paragraph should start with a take-home message and followed by supporting evidence with figures and statistics. But the subject of EACH sentence should be a metric or idea in your study and NOT the Figures or Statistical method as the topic of a sentence.

• Figures and statistics should only be reported in parentheses to support any assertion your make about your results.

>   That means: DO NOT write:
>
>   > • Figure 1 shows that variable X is greater in condition A than condition B.
>   > • Paired t-test show that A is greater than B.
>
>   DO write:
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>   > • Muscle resistance to stretch is greater in small versus large pre-stretch conditions (Figure 1). Both short-range stiffness and impulse were greater in pre-stretch amplitudes < 1% compared to >3% (paired t-test; delta SRS: mean ± SD, $p < 0.01$; delta impulse: mean ± SD, $p < 0.01$)

• Most of the time the really good results summary sentences are written in the discussion section. So don't delay in writing your discussion section, if only to improve your results section. Similar to writing the abstract early, this is the part in which you're forced to succinctly encapsulate your findings. I love mining the discussion section for nice gems to put as lead sentences for paragraphs in the results section.

• **Guide the reader through each and every panel of the figures.** Although you don't want to explicitly refer to figures, each figure is there for a reason, and you need to tell the reader what it is there for. Make sure that you don't simply report results, but use a narrative to walk them through it, as you would in a talk. You can describe features to look at in raw data to explain the features selected for groupwide or between-individual comparisons.

For example: "There were a widely differing peak latencies and multiphasic oscillations observed across participants (see exemplars in Figure X)." In an individual with poor balance, latencies were later and responses has more peaks (see exemplar, Fig. XA, red trace) than an individual with no balance deficit who exhibited a single, early peak (see exemplar, Fig. XA, blue trace). Across all individuals, longer peak latencies were correlated to lower MiniBEST balance scores (Fig XB $r^2 = XX$, $p < 0.01$).

• **The discussion should start by explaining your results and then explaining the impact.** Going with our table, we have lots of explaining to do about how we interpret what we found. Of course, if you have 9 figures, you won't need 9 paragraphs, but you will need to find an organization structure to first convince people that your results are sound, interpretable, and make sense BEFORE you go on to make any proclamations about future impact.

The general structure of the discussion should be as follows:

>   • First paragraph as a summary of the discussion. Start with the take-home message, and end with impact to the field. If you do this right, each sentence can be the topic of one of your discussion paragraphs, so good to write this when you start.
>   • Next couple paragraphs need to establish the validity of your results. Make sure to discuss them in the context of prior findings, establish that appropriate controls were made, and talk about potential biases or problems with your study that you've thought of and explain how they are not expected to change your basic conclusions. This is why they should go in the same order as the results. Its often hard not to simply repeat results here more succinctly (which you'll move to the results section), but you need to say WHAT IT MEANS.
>   • The last one or two paragraphs can be prospective in nature. What do your results imply in the long-term. How can it affect the future of rehabilitation, or our understanding of sensorimotor control?

• **Show off your knowledge of the literature in the discussion.** Here is where your knowledge about the field can shine, and you can make people happy by citing them and explaining the importance of their work as a foundation to yours. But this is not a free-ranging discussion, but a place to show how your findings build on, contradict, or unify prior literature. It is also a place to interpret your findings withing the field. Plan to explain what others have found and how they mesh with your findings. Be upfront about an contradictions with prior literature. Think about the first-year graduate student reading your paper and needing a bit of a primer in the field and a reading list. Think of the scholar in the field you want to read your paper--let them know you understand and respect their work. It ok to cite things not for what the authors said, but for something you noticed in their data.

EXAMPLES

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Check out the abstract and introduction structure in this paper.
https://www.science.org/doi/10.1126/scirobotics.adf1080

We wrote the abstract after a decent first draft, and used it to sharpen the paper and choose the vocabulary we wanted to use to talk about our paradigms and results.

The introduction is aimed at justifying the experimental conditions, and the associated metrics that we report.

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Here is a modeling paper where each paragraph in the introduction motivates a particular element that we introduce into our model and that we systematically manipulate in our results.
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0205763

The last sentence in each introduction paragraph explicitly explain a metric or test that we evaluate in our study.

The last paragraph of the results summarizes what we did, and is completely unsurprising based on the introduction.

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Here is an experimental paper where each paragraph in the introduction motivates a particular experimental paradigm or metric and explains predictions that we test.
https://www.frontiersin.org/articles/10.3389/fnagi.2021.742243/full

The last sentence in each introduction paragraph explicitly explain a metric or test that we evaluate in our study.

The last paragraph of the results summarizes what we did, and is completely unsurprising based on the introduction.

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What if you have a really complex paper that has a lot of figures that can't all be explained in the introduction? Many journals limit the length of the introduction.
https://elifesciences.org/articles/55177

This is a paper we struggled with. At one point the introduction was very, very long. In the end, it is only 3 paragraphs long, focusing on the gaps in the literature that the work fills. Many of the limitations motivating each choice and each figure are packed into the introduction paragraphs.

All the explanatory "background" stuff is in the discussion.