Between the Lines: How Scientists Write, Why It Matters, and What Shapes Their Choices

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Hohmann, MH & Connell, SD 2025, 'Comparing the writing styles of highly and rarely cited papers in conservation biology', *Biological Conservation*, vol. 307, DOI: 10.1016/j.biocon.2025.111125.

Abstract

Science is a process of collaboration where scientists build upon previous research to develop more knowledge than would be possible on their own. Science communication is an emerging field of study which aims to explore the best ways of sharing knowledge. Despite an increasing focus on this area, academic writing is still generally difficult to understand. Here, I examined the ways in which scientists write in scientific journals.

I explored how scientific writing has changed over time. I analysed over 20 million abstracts to see the changing popularity of writing features. I found some areas of positive change such a reduction in hedging terms and an increase in active narration. But there were also negative changes such as an increase in sensational language. This indicates that scientists are putting some effort into improving their writing, but progress remains to be made.

To test how these changes impact readers, I studied the impact that different writing styles can have on peoples' ability to recall information from a scientific text, as well as the impact writing has on peoples' subjective experience of a text. I found that readers were much more likely to recall information and had more positive feelings about the text when it was written clearly. I also report preliminary results from an electroencephalograph's measure of brain activity.

I found that clear writing can also benefit writers. I analysed 500 rarely cited and 500 highly cited papers to see if there was a significant difference in writing style. I found that several aspects of writing are linked to increased citations. It should be noted that these features were also associated with journal impact factor and the causal relationships remain unclear. I found that writing features such as a reliance on broad language and visual elements were positively associated with high citations.

I also investigated whether scientists are taught the skills they need to write in this easily understandable way. I tested university students to see how numeracy skill, literacy skill, and overall academic success affect one another. I found that numeracy and literacy both contribute to academic success. In addition, literacy is associated only with engagement in fiction texts. This suggests that actively teaching science students literacy skills can forge more successful scientists. However, universities tended to avoid putting successful researchers in coordinator positions for writing courses.

In addition to helping researchers develop skills, universities are key to helping them publish. I analysed 200 researchers from differently ranked universities. I found that there was no significant pattern in open access versus pay-walled publishing as a result of university rank. In addition, I found that the differences in publishing behaviour between institutions have been narrowing since the early 2000s.

I hope that I can provide insight into why we write, why it matters, and what shapes scientists' choices. These insights may be used to inform institutions about how they can support researchers in developing their communication skills, so that we can move towards a world where science communication is as effective as possible.

Thesis Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

I give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

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Chapter 1: General Introduction

Science has always been a process of collaboration, where a range of people build upon the ideas that came before in order to develop a deep understanding of the world around them. Through this process, we are able to reach a state of knowledge far more extensive and sophisticated than any individual could achieve alone. But this process can only function as long as scientists are able to understand one another. The development of robust public education systems and – more recently – the rise of the internet and social media have allowed for new avenues of science communication. But peer-to-peer communication still heavily relies on the written word as distributed through journal articles.

Being able to write clearly worded journal articles is vital for the process of science. No matter how significant a researcher's work is, it must be *understood* in order to contribute to a field. Therefore, it benefits researchers if they are able to develop a command of language in order to help people understand their work.

Scientists who apply themselves to mastering the skill of scientific writing will not only help their fellow academics understand and build upon their work, but they can also help non-scientists engage with their work. In recent years, there has been an increased focus on the democratisation of knowledge outside of traditional academic spheres. It is generally agreed that granting people access to as much knowledge as possible is a social good. The rising popularity of open-access publishing since the early 2000s is just one example of this (Piwowar et al. 2018). But making scientific literature available to the public is of little value if said literature is so dense and jargon-filled that even experts struggle to understand it.

Being able to use clear, precise language is therefore an invaluable skill for researchers. Words are what we use to communicate meaning to others (Bazerman 2013). Over the past several years, many different types of writing such as news articles and political speeches have trended towards increasingly simple language (Hou & Smith 2021; Plavén-Sigray et al. 2017). But this is not the case in science where – despite their crucial nature – many journal articles are written using dense language and an unintuitive structure which makes them difficult to understand (Hillier, Kelly & Klinger 2016; Plavén-Sigray et al. 2017; Ryba, Doubleday & Connell 2019; Seymour et al. 2015). For just one example, current medical articles are as difficult to comprehend as legal contracts (Yeung, Goto & Leung 2018). To make matters worse, many researchers have found evidence that the readability of scientific tests is actually *decreasing* over time (Barnett & Doubleday 2020; Graf-Vlachy 2021; Jeong, Rogers & Washispack 2021; Plavén-Sigray et al. 2017; Vergoulis et al. 2019).

It is generally assumed that researchers who have reached a professional level in their academic journey can easily understand scientific articles regardless of how well-written those articles are. But there is evidence to suggest this is not the case. For example, one study estimated that around one quarter of citations used in marine biology papers did not support the point they were references for. In 10.6% of cases the citation offered ambiguous support and in 6% of cases the citation offered no support for the for the statement in question. While some of this could be the case of deliberate misrepresentation, it is also likely that at least some of this discrepancy is a result of honest error (Todd et al. 2010).

Outside of a professional context, we should also ask how these trends might impact the general public. If even scientists struggle to understand scientific articles, it is no wonder than members of the public turn to snappy summaries posted to social media. This is not to discount the value social media has as an educational tool. Social media offers scientists a chance to connect to a wider audience than ever before. However, the lack of peer review leaves the door open for bad actors such as anti-vaccine activists and climate change denialists (Seymour et al. 2015). For example, while there is no significant difference in writing quality between pro and anti-vaccine news articles, in pro-vaccine articles poor readability was correlated to low engagement, whereas no such trend was found in anti-vaccine articles (Xu, Ellis, & Umphrey 2019). Similarly, articles published in peer-reviewed journals are less readable than articles published in “throwaway” journals (Rochon et al. 2002). This means that readers might be driven to less reliable journals purely because the articles there are more understandable to them.

By focusing on using easy to understand language, scientists can help these members of the public understand scientific findings and apply this knowledge to their lives (Bauchner & Rivara 2022; Vergoulis et al. 2019). In contrast, unclear writing reduces the capacity readers have to understand and recall information found in a paper (Britton et al. 1982; Sweller 1994). This contributes to a culture where scientific studies are impenetrable to non-experts, who may struggle to understand the significance and development of science. This means that scientists are not taking full advantage of the rise of the internet, which *should* allow science to be shared with a wider audience than ever before (Bowman & Bozich 2015). A strong scientific writer should be able to support understanding in their audience by writing in a way which balances both clarity and precision (Alley 1996; Doubleday & Connell 2017).

The issue of poor writing has not gone unrecognised by the scientific community. Scientists have been advocating for better writing for decades (Macphail 1911; Meredith 1966; Peterson 1961; Smith 1915). Much ink has already been spilt from researchers debating the best ways scientists can use language to engage with and inform the general public, and how they can best communicate among themselves (Montgomery 2003; Sword 2012; Pinker 2014).

This level of concern demonstrates that it is important to consider the modern-day practice of scientific writing and which elements of writing best support reader understanding. In this thesis, I have attempted to explore the ways the practice of scientific writing has changed over time, the potential impacts these changes have on readers, the potential impacts these changes have on writers, the ways in which scientists are (or, more often, are *not*) taught how to write, and the possible facts driving the changes in scientists' publishing habits. But in order to start investigating these issues, we must first decide how to measure the quality of a piece of writing.

1.1 Measuring Writing Quality

A common framework for understanding writing quality is the theory of cognitive load. Cognitive load is a theory which attempts to explain the best ways to present information for the ease of a reader. The theory assumes that – as working memory is limited – people can only "hold" a few pieces of information at a time, with any additional information being quickly forgotten. While information can be transferred from working memory into long-term memory, doing so requires some level of understanding of the ideas in question (Sweller, van Merrienboer & Paas 1988).

There are three primary measures of "cognitive load". These are: intrinsic, germane, and extrinsic. Intrinsic load refers to the inherent complexity of the topic (for example, theoretical physics is more complex than basic addition). Germane load refers to the impact of prior knowledge on the part of the reader (for example, an academic in the field of ecology will experience less cognitive load when reading an ecology paper compared to a layperson). In contrast to the other two features, extrinsic load refers to cognitive load unrelated to the specifics of the topic. It is this aspect of cognitive load which is most important to this thesis, as it can be reduced by writing techniques such as strong grammar, clear structure, and avoiding undefined jargon (Jeong, Rogers & Washispack 2021).

In general, papers which are written with an eye for reducing cognitive load through clear writing results in a readership with a greater understanding of the paper, as well as increased confidence in their understanding (Ryba et al. 2021; Sweller 1994). The cognitive load readers experience can

be reduced by changes to the writing style, for example by shortening sentences and using less complex vocabulary (Britton et al. 1982). Two different papers may be roughly similar in terms of the complexity of information they provide but can still differ in terms of how much mental effort is required to understand them due to the way in which they were written.

But, given the importance of writing quality, how do we measure it? Writing quality – and by proxy, cognitive load – can be tested in a number of ways (Ayres 2006; Britton et al. 1982; Sweller, van Merrienboer & Paas 1988; Sweller 1994; Wang, Fang & Gu 2020). One of the most common methods is readability matrices. Readability matrices are a mathematical tool used to determine how difficult a text is to read. There are several different matrices which all use slightly different formulas, though most rely on a measure of sentence length and the complexity of vocabulary. There is some debate as to their effectiveness, but nonetheless they remain very popular in the field of science communication (DuBay 2004).

The debate around the effectiveness of readability matrices mainly focuses on the fact that these matrices do not account for the overall structure of a text. By virtue of their simplicity, they generally only focus on very specific aspects of readability such as sentence length. It is possible that the overall structure of a paper either increases or decreases clarity and cognitive load in a way which these matrices cannot detect (Begeny & Greene 2013; Redish 2000). Some researchers have reported that there is only a weak association between these matrices and reading comprehension in children and that the matrices often disagree with each other (Begeny & Greene 2013). Others have found that readability matrices perform poorly when it comes to predicting how adults judge their own understanding of the text (Crossley et al. 2017).

So, while these matrices can be very useful – especially when it comes to exploring widespread trends across large databases – they have some common blind-spots. Fortunately, there are methods for studying readability that do not rely on these matrices (Hartley 2000; Hillier, Kelly & Klinger 2016; Ryba, Doubleday & Connell 2019). For example, modern technology has allowed for direct measurement of cognitive load via brainwave patterns. One of the most informative testing methods is the use of an electroencephalograph (EEG), which offers continuous, real-time data about the level of concentration a piece of writing asks from its readers (Antonenko 2010). This objective physiological measurement can be used in tandem with traditional subjective measures such as self-reported mental effort (Brunken, Plass & Leutner 2003).

However, such technology is reliant on directly testing a human subject and as such cannot be used to analyse a piece of writing *in situ.* But there are methods for doing so. Readability can – instead – be tied to several text features. These features include the use of clear scene-setting and consistent language (Ryba, Doubleday & Connell 2019). Readability has also been tied to "narrative" writing styles (Bower & Clark 1969; ElShafie 2018; Hillier, Kelly & Klinger 2016). In addition, using active verbs can make it a lot easier for readers to predict the structure of a sentence (Coleman & Blumenfeld 1963) and can provide a clear mental image to the reader (Derewianka 2012). On the subject of imagery, literal visual elements are very closely linked to audience engagement (Kim et al. 2002; Pérez-Llantada & Luzón 2019).

Even the title of a paper can have a significant impact on audience engagement (Jamali & Nikzad 2011). The use of field-specific jargon in the title and abstract of a paper is negatively correlated to the number of citations it receives. Jargon is an interesting case, as it can be valuable for distilling complex topics. However, this is only true if the reader is already familiar with the topic and if they are not then jargon can render abstracts impenetrable (Martínez & Mammola 2021).

Another commonly studied aspect of scientific writing is words used to signal uncertainty (often referred to as "hedging" words), or their converse, "hype". The use of hype has consistently been found to have increased over time (Mammola 2020; Millar, Batalo & Budgell 2022; Vinkers, Tijdink & Otte 2015), while in contrast, hedging words have significantly decreased in popularity over the past 25 years (Yao, Wei & Wang 2023). This is not necessarily a positive change. While an article which contains a significant amount of hype can more easily attract new readers who are more likely to be convinced of the article's thesis (Boutron 2014), this reliance on positive framing may over-emphasise the significance of the results (Chiu, Grundy & Bero 2017). But this writing style persists, partially due to the pressure placed on researchers to continually publish innovative and ground-breaking research which is widely cited (Hoekstra & Vazire 2021; Jawaid 2016).

1.2 Readability and Citations

On the subject of citations, many previous papers have examined the potential links between writing quality and citation frequency. However, these papers often draw conflicting conclusions. In operations and supply chain management papers, increased readability has a positive impact on the number of citations a paper receives and these positive impacts last over a long period of time (Jeong, Rogers & Washispack 2021). Other fields show similar results (Martínez & Mammola 2021; Sawyer, Laran & Xu 2008; Ryba, Doubleday & Connell 2019; Vergoulis et al. 2019).

But not all researchers agree that more readable language is associated with increased citations. A study focusing on articles in the field of technology found that more complex texts were more likely to be cited at least once. In particularly common fields of study, the top 1%-10% of cited articles were often the least readable (Ante 2022). Similarly, the readability of information science papers is not significantly associated with the number of citations these papers receive (Lei & Yan 2016). Other studies reflect similar findings (Dolnicar & Chapple 2015; Stremersch, Verniers & Verhoef 2007).

Despite disagreeing on the exact effects of readability on citations, both "camps" generally agree that clear writing is important. Even the papers that did not find a positive relationship between citations and readability stress that this means that authors have little incentive to improve their writing. This can lead to errors spreading through the scientific field, as readers misinterpret unclear papers due to poor writing choices (Britton et al. 1982; Dolnicar & Chapple 2015; Lei & Yan 2016). This means that further investigation is needed to determine exactly how readability affects engagement with a text.

1.3 Teaching Scientific Writing

It is all well and good to stress the importance of researchers developing their writing skills. But for many, this is easier said than done. Many graduate and post-doctoral students agree that they haven't been suitably trained in writing skills during their studies and lack confidence in their abilities (Glew, Challa & Gopalan 2014; Kamler 2008). In fact, it has been estimated that around 72% of science graduate students are not taught science communication at a university level (Ritchie et al. 2022). Even among students transitioning from undergraduate report-writing to graduate-level writing for publication, there are few opportunities for them to take courses focusing on scientific writing for the purposes of publication (Nolan & Rocco 2009).

This idea is furthered by the existence of strong support among current students for: at least one doctoral-level course on writing a professional publication, beginning instruction in writing earlier in their tertiary education, designing class assignments that are more in-line with official journal publication requirements, and providing opportunities for peer or instructor review of manuscripts (Jalongo, Boyer & Ebbeck 2014). Despite this, writing is often an assumed skill rather than being taught (Hodges & Narum 2015) and it seems like most researchers have to learn how to write and publish papers by mimicking their colleagues (Bornmann 2010; Negretti, Persson & Sjöberg-Hawke 2022).

Writing courses are not solely useful for the purposes of ensuring publication. There is evidence to suggest that having well-developed writing and reading skills can aid the scientist themselves in their broader studies. A positive correlation between literacy and numeracy skills has been found in several papers (Adelson, Dickinson & Cunningham 2015; Ajello, Caponera, & Palmerio 2018; Allen 2014; Beal, Adams & Cohen 2010; Gomez et al. 2019; Graham et al. 2017; Isphording, Piopiunik, & Rodríguez-Planas 2016; Korpershoek, Kuyper, & van der Werf 2015; Laere, Aesaert & van Braak 2014).

In a 2013 paper, Pyburn et al. examined the language comprehension ability, maths ability, prior chemistry knowledge and course performance of chemistry students in an entry-level university course over a two-year period. They found that language comprehension was positively correlated to general chemistry ability and was even able to partially compensate for a lack of prior chemistry knowledge. In response to these results, it is suggested that universities make further efforts to support the language skills of students (Pyburn et al. 2013). Despite these clear benefits and calls from the students themselves, many universities continue to lack support for Science, Technology, Engineering, and Maths (STEM) students hoping to develop their writing skills. In addition, students report a lack of knowledge about the publishing process (Jalongo, Boyer & Ebbeck 2014).

1.4 The Rise of Open Access

The lack of formal training in the publishing process is a particular issue as the landscape of publishing has been changing rapidly in recent years and so “common practice” may well be out of date. One such example is the rise of open access publishing, which has been steadily growing in popularity over the last few years (Lal & Lal 2011). Researchers have developed diverse frameworks for understanding the potential benefits and goals of open access publications. These frameworks focus on: the distribution infrastructure for scientific papers, the general public’s access to the process of science, the importance of open access for promoting interdisciplinary collaboration, alternate techniques for measuring scientific impact, and the democratisation of knowledge (Fecher & Frieskie 2014).

Ideally, open-access publishing will allow a wider range of people to access scientific literature. It has been found that while open-access papers may not be more frequently cited, they have a broader audience and are more frequently read. This indicates that there is an audience who will consume scientific papers for purposes other than citing them (Davis 2011). Other studies are even more positive, with findings indicating that open access papers were cited 18% more on average. These researchers also found evidence that open access is growing in popularity over time

(Piwowar et al. 2018). Open access has seen particularly strong growth in lower-income countries, suggesting it is especially beneficial there (Karlstrøm, Piro & Aksnes 2024).

There are several benefits to open access publishing. Firstly, traditional journals which charge subscription fees to their readers have little monetary interest in publishing a wide range of papers and therefore their acceptance rate can be as low as 8% (Van Noorden 2013). Another key argument in favour of open access is that – as scientific research is commonly funded by the government – placing the resulting research behind a paywall forces the taxpayer to "pay twice" for research that should be freely available to them (Frank, Foster & Pagliari 2023). Open access also means that academics and their institutions can save money on subscriptions to journals (Knoche 2020).

However, there are valid concerns about the possible negatives of this form of publishing. For example, open access publishing can be extremely expensive (Van Noorden 2013). These costs have been cited as a major barrier to publishing open access by up to 86% of researchers (O'Hanlon, McSweeney & Stabler 2020). This allows for predatory publishing practices on the part of the publishers such as not disclosing publishing fees until a paper is accepted for publication (Beall 2012). There are also concerns that the increased cost of publishing often associated with open access is discriminatory against less well-funded researchers (Frank, Foster & Pagliari 2023; Mekonnen et al. 2021). The profit incentive also encourages open access publishers to publish as much as possible regardless of the academic merit of the papers in question (Frank, Foster & Pagliari 2023). In general, modern open access practices are largely profit-driven, at least when it comes to privately-owned publishers (Knoche 2020).

While the profits incentives on the part of the publishers remain, there have been efforts to address the issue of overly expensive publishing charges. Read-and-publish agreements between institutions and publishers are an example of a system which has been introduced to help combat this inequality (Hunter 2019). However, these systems have also come under criticism for supporting publishers at the cost of academic libraries (Odlyzko 2015).

1.5 Thesis Structure

While there are many avenues for modern-day science communication, I chose to focus on journal articles due to the critical role they play in sharing scientific findings. In this thesis, I attempt to determine which styles of writing best facilitate this sharing and how to encourage authors to use this style. I will explore this by examining the temporal shifts in academic writing style, the effect of

reducing cognitive load on readers through clear writing, the benefits academics might see from focusing on clear writing, how current science students are supported in terms of developing writing skills, and the factors influencing where academics choose to publish. Each of these factors have a key role to play in the current state of academic writing.

I chose to start my investigations by exploring how the style of scientific writing has changed over time and if these changes are for the worse or for the better. This will give insight into if the recent push for clear scientific writing has actually affected scientific literature as a whole, or if it is merely a vocal minority advocating for these changes. In Chapter 2, I extracted twenty million scientific abstracts from the PubMed database and tracked the changes in frequency of use of a number of key writing features over the past seventy years. Knowing which writing features have been changing in frequency will tie into subsequent chapters which explores the impact of writing style on reader understanding and citation impact.

In Chapter 3, I aimed to investigate how changes in writing style can impact the readers of scientific papers. In conjunction with Chapter 2, this will provide some broad insights into whether scientific literature is becoming more reader-friendly or not. While there are many options for exploring the impact of writing style on readers, I chose to focus on direct measurements of recall and subjective experience as reported by readers. Specifically, I provided each subject with two different scientific abstracts – one written well and one written poorly – and observed the resulting changes in recall, ease of understanding, confidence in understanding, and enjoyment. I also provide preliminary results from a brain-imaging test.

But readers are only one side of scientific writing. It is also important to consider the potential impacts on researchers. In Chapter 4, I investigate these indirect effects of writing style. I analysed 1,000 papers (500 rarely cited and 500 highly cited) to see which writing features were linked to increased citations. In doing so, I hoped to test if clear writing is correlated to increased citations. While similar studies have been done in the past, they often conflict with one another. Hence, I thought it would be a valuable avenue for investigation which would provide further evidence one way or the other.

Aside from any potential positive or negative effects on readers and writers, it is well-known that researchers often lack the training needed to write in a clear and insightful manner. Therefore, in Chapter 5 I wanted to investigate the links between university student success, literacy skill, and numeracy skill. I tested several third-year biology students on these skills in order to compare the

relationships between them. While these links have been studied in the past, I hoped to add more insight to the study of the intersection between these types of skill. In particular, I wanted to gain insight into the relative importance of engagement with fiction as opposed to nonfiction for developing literacy skills. This chapter aims to provide insight into whether universities are providing appropriate support for their students in order to enable them to develop into successful researchers.

But writing is only one component of being a successful researcher. An understanding of the publishing system is also critical for career academics. It does not matter how well an academic can write if they are unable to distribute their papers. In Chapter 6 I aimed to investigate a few of the factors that might influence researcher publishing habits. In particular, I wanted to see what factors might influence researchers to publish in open access as opposed to pay-walled journals. I hypothesised that researchers from lower-ranked – and less well-funded – institutions might preferentially publish in pay-walled journals due to the often-significant cost of open-access publishing fees. I used several databases to examine the publishing patterns of a number of universities – some high-ranking and some low-ranking. I also examined the publishing patterns of 200 academics from these universities. While open access publishing is somewhat controversial as a system, it does offer an opportunity for a wider range of people to engage with science and as such an understanding of the factors influencing its popularity is a key part of the study of science communication.

Through these five avenues of exploration, I hope to help answer the questions of how scientific writing is changing, the effect of these changes, and how institutions can best support their researchers. With these answers we can develop an understanding how what styles of writing are best for both readers and writers and how to encourage researchers to embrace these writing styles.

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The evolution of scientific writing: an analysis of 20 million abstracts over 70 years in health and medical science

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Abstract
For at least a century, scientists have been concerned with the need for clear scientific writing. This concern has grown with the advent of the internet allowing for global, interdisciplinary collaboration. In this study, we used R software to analyse over twenty million abstracts from scientific papers in the health and medical fields — tracking changes in the frequency with which different writing components have been used since the 1950s. This historical understanding provides insight into our past writing cultures, how they have changed, and where we stand as science communicators today. We found that scientists are increasingly using writing components that reduce cognitive load and improve reader understanding. Despite these positive efforts we found that many scientists still feel a need to adhere to 'The Official Style' that falls back on dense and difficult prose. We advocate for more accessible science writing so that its discoveries not only encourage inter-disciplinary research, but are also spread across wider society as part of the sharing of knowledge.

Keywords Science communication · Interdisciplinary · Readability · Scientific writing · Traditional style

Introduction

Knowledge is often thought to be power. While historically the acquisition and spread of knowledge was the domain of those not otherwise engaged in manual or routine labour, the modern era has seen knowledge become increasingly accessible across a wider part of society. Yet the democratisation of knowledge from within the sciences has been slow. Early scientific writing of the seventeenth century was characterised by emotive, compelling narrative techniques intended to inspire the audience. For example, take Isaac Newton's 1672 letter which reads, "In the year 1666… I procured me a triangular glass prism, to try

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therewith the celebrated phaenomena of colours… It was at first a very pleasing divertissement, to view the vivid and intense colours produced thereby… I became surprised to see them in an oblong form; which… I expected should have been circular" (Montgomery, 2003). But some argue that over time, scientific writing settled into a form characterised by strict structure and dense prose (Montgomery, 2003). It seems that scientists are no longer expected to use the written word skilfully (Montgomery, 2003; Ritchie et al., 2022). Scientific knowledge is generally inaccessible because it lies behind a linguistic wall, restricted by access to scientific journals and limited by scientific jargon. Scientists complain about the difficulty of reading research from within their own speciality (Ryba et al., 2019; Todd et al., 2010). If scientists struggle to comprehend their own field, then scientists from other specialities — and certainly laypeople — will struggle more. By writing in a manner which is easily understood by a wider range of people, scientists can ensure that the time they invest in writing is as comprehendible and impactful as possible.

Every scientist relies on the written word to communicate their findings with the world. Words are what we use to create these meanings and influence our readers (Bazerman, 2013). Yet the archetypical image of a scientist generally focuses on the activity of research, such as a scientist combing the wilds of the Amazon, or in a lab full of colourful beakers. This image fails to account for the fact that many scientists occupy most of their time with writing or reading. This mis-match of image and reality may devalue the practice of researchers investing time into more accessible writing. Scientists are both taught to and expected to write in 'The Official Style'. This style is a formulaic system of writing used in a wide range of non-fiction contexts. It is generally characterised by a heavy use of jargon, passive voice, and a "detached" authorial voice. These components can place an increased cognitive load upon the readers and make the text harder to digest (Lanham, 1979). In contrast, the benefits of accessible science centres on the transfer of information. Science can perhaps best be understood as a collaborative, interdisciplinary work spread via the written word. This raises the question as to whether we as scientists have developed our communication skills over time and if we have made our research accessible to scientists outside our discipline and broader society.

Accessible and comprehendible writing is important. Perhaps most obviously, clear writing allows members of the public and other non-specialists to understand the processes and implications of scientific studies. Sharing their findings is an essential duty of a scientist, so it behoves researchers to ensure that they write in a manner which is readily understood by a wide range of people (Vergoulis et al., 2019). Clear writing can also help to improve communication within scientific fields (Britton et al., 1982; Dolnicar & Chapple, 2015; Lei & Yan, 2016). Clear writing has been linked to an increased number of citations — a major concern for all research-focused scientists (Martínez & Mammola, 2021; Sawyer et al., 2008; Vergoulis et al., 2019). In addition, misrepresentation of research is prevalent within journals. For example, around a quarter of citations used in marine biology papers do not support the points they claim to (Todd et al., 2010). While some misrepresentation is deliberate (Chiu et al., 2017), it is also likely that some is due to accidental misinterpretation of papers. This is important because science is an interdisciplinary field built on holistic problem-solving and the integration of knowledge from multiple fields. Scientists need to be able to understand one another to reap the benefits of collaborative research. There is also a risk that news media — faced with confusingly-worded research — will represent this research inaccurately.

Cognitive load is one theory that can help us understand how writing styles affect reader comprehension. Cognitive load is a concept that refers to how much mental effort a reader must put forth to comprehend a text and how information can best be presented in a way

which is easily understood (Sweller et al., 1988). Cognitive load can be reduced — and therefore understanding can be increased — by differences in writing styles. For example, using shorter sentences and simpler words reduces the cognitive load of a text (Britton et al., 1982; Jeong et al., 2021). Two papers may be the same in the complexity of the information being conveyed, but the way they are written can affect how much mental effort is required from the reader. Writers can assist readers in the learning process by focusing on the structure and form of their work, with the aim of reducing cognitive load (Sweller, 1994).

However, many articles require a high level of cognitive load, especially for non-expert readers (Plavén-Sigray et al., 2017; Seymour et al., 2015) and even expert readers can struggle with unclear writing (Hillier et al., 2016; Ryba et al., 2019). This matter has been a concern for scientists for over a century (Macphail, 1911; Smith, 1915) and this concern has only grown over time as unclear writing continues to restrict the reach of scientific knowledge (Graf-Vlachy, 2021; Jeong et al., 2021; Plavén-Sigray et al., 2017).

To explore the merits of these concerns, we assessed how the overall style of scientific writing has changed over the last 70 years. We examined over twenty million scientific abstracts for nine key writing components. These components were chosen from previous research which examines the key elements of clear scientific writing. Previous researchers have already found that using certain specific writing components can improve the impact of scientific papers (Ryba et al., 2019), but there has been little research into how these components have changed in frequency of use over time. The components chosen spanned different linguistic domains, such as grammatical (nouns, verbs), semantic (emotional expressions), and pragmatic (heading words) to investigate whether their frequency of use has shifted over time. The writing style of a paper is determined by the specific writing components used. Writing styles can differ in terms of clarity, where "clearer" papers induce less cognitive load on the reader. Given the impetus for researchers to increase the impact of their scientific papers, we hypothesised an increase in usage of writing components known to improve clarity and reader engagement (see "Methods").

Methods

We digitally analysed 20, 876, 733 abstracts from scientific papers, dating back to the 1950s. We used R Version 4.2.0 for this process (R Core Team, 2022). The complete R code to create the data and analyses are available here: https://github.com/agbarnett/narrator.

We tracked changes in the frequency with which certain key writing components were used over time on an annual basis. These components could either benefit or impair the reader in understanding a paper (Ryba et al., 2019). This analysis is intended to provide insight into how scientific writing has improved or declined in quality over time. While abstracts are generally less readable than the full paper, there is a strong correlation between abstract readability and article readability (Plavén-Sigray et al., 2017).

The data were extracted from the PubMed baseline repository of health and medical journals provided by the National Library of Medicine via its API. The data were updated by the National Library of Medicine on the 13th of December 2021 and downloaded in XML format on the 22nd of June 2022. Although the PubMed repository includes papers going back to the year 1781, we used 1950 as the first year because the number of abstracts before this year was relatively small.

Abstracts were excluded if they were empty, had 5 words or fewer, were not in English, were a duplicate, or were missing the article type. The total number of abstracts excluded and plots of exclusions over time are in Supplementary File II.

Abstracts were processed to remove unnecessary text and ease the process of extracting the writing characteristics. Common symbols and non-ASCII characters were changed into words, for example "&" was changed to "and". We removed sub-headings such as "Introduction" and "Methods". We removed any standard text on copyright.

Keywords were searched after converting the text to lower-case. The keywords used for each writing characteristic are listed in Supplementary File II. For each abstract we collected data on the article type, number of authors, country of first author, and number of words. It is important to note that accurate measures of article type are often difficult to obtain as papers are often categorised inconsistently by in-built search filters (Salvador-Oliván et al., 2021). However, we estimate that 16, 418, 414 of the papers in our corpus were journal articles.

We used random checks to verify the data processing and extraction. We checked three randomly selected abstracts with and without each of the writing components to verify that they were appropriately present or absent. We also checked abstracts that had very high counts for each writing component.

We did not use statistical models, but instead simply plotted the annual trends over time as this provides the necessary information on the size and pattern of the trend. Given the very large data set, any statistical tests will almost certainly reject the null hypothesis of no change over time (Wasserstein & Lazar, 2016). We focus on the size and meaning of the changes, rather than statistical significance (Fig. 1).

The writing components examined represent a broad set of components known to aid reader engagement. We detail the writing components used (below), many of which are associated with citation rate (Ryba et al., 2019). An explanation for this impact on citations was offered by Freeling et al. (2021), showing that an increase in sign-posting and active narration, accompanied by a decrease in noun chunks and hedging was linked to greater readability. Where readability is experimentally increased under controlled and replicated conditions, readers report higher levels of confidence in their understanding and demonstrated a more accurate understanding of the primary aim and messages of the paper (Freeling et al., 2021).

We also investigated well-researched writing components that span sentence structure (sentence length), use of grammar (verbs), semantic expressions (sensational words) and numbers.

- The use of short sentences has such a renowned influence on clarity that it is often included in indices used to rate readability (e.g. Dale-Chall Readability Matric, Flesch-Kincaid Grade Level, Gunning Fog (or FOG) Index, Lexile Framework, Powers Sumner Kearl Readability Formula, Fry Readability Formula, and Spache Readability Formula (Begeny & Greene, 2013).
- The use of active verbs (e.g. expressing actions performed) (Coleman & Blumenfeld, 1963) and motivational language (e.g. sensational or energetic words) (Mammola, 2020; Vinkers et al., 2015) conveys a sense of direct and dynamic engagement making sentences more engaging compared to passive language. Verbs can convey ideas clearly and precisely (Fairbairn, 2012; Last et al., 2019) and well-chosen active verbs can create visual imagery to paint a clear and engaging picture in the reader's mind (Derewianka, 2012). We examined the average use of motivational language and active verbs per 100 words within each paper's abstract.

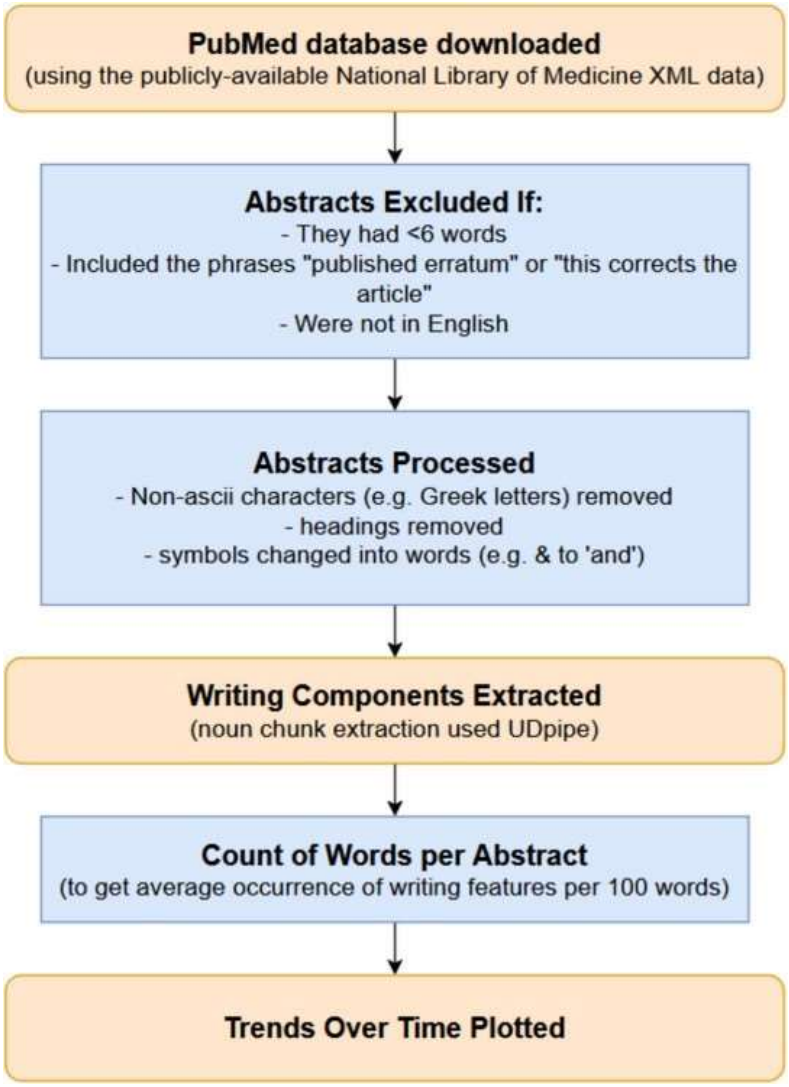

Fig. 1 A flowchart of the methods used to process the data for this study

- In contrast to active verbs and motivational language, the overuse of numbers in scientific papers can increase cognitive load unduly for the reader (Miller, 2004).

We examined several components of narrative writing. Audiences are more able to understand and recall narrative structures compared to traditional academic writing (Bower & Clark, 1969; Hillier et al., 2016). The components we examined were:

- Sign-Posting: words which denote order and/or cause and effect, which helps the audience keep track of how ideas relate to one another (Hillier et al., 2016; Lindsay, 2011; Montgomery, 2003).
- Active Narration: personal language, which helps audiences relate to the text (Hillier et al., 2016; Pinker, 2014; Sword, 2012).
- Verbs: "active" words, which impart a sense of action unto the text (Derewianka, 2012; Fairbairn, 2012; Last et al., 2019).

Hedging Words: useful for expressing uncertainty where it exists in the research, but also means that readers have less confidence in the writing (Montgomery, 2003; Pinker, 2014; Sword, 2012). In contrast, reduced hedging increases the positivity of the writing and increases the confidence the audience has in the study, which is beneficial for promotional purposes (Yao et al., 2023).

Length of Sentences: we did this by tracking the frequency of full-stops, selecting only for those used at the end of a sentence. Most methods for judging the readability of a text support the idea that shorter sentences are more readable (Britton et al., 1982; Jeong et al., 2021).

Noun Chunks: estimated by converting the data into universal part of speech tags using the "udpipe" package (Wijffels, 2022). Noun chunks provide a "stumbling block" in the reading experience which increases cognitive load (Lindsay, 2011; Montgomery, 2003; Pinker, 2014).

Numbers: the amount of mathematical equations in a paper negatively affects the number of citations a paper receives (Stremersch et al., 2007).

Individual Nouns: while noun-use is not linked to readability, they are an important element of linguistic structure (Crossley et al., 2017).

Sensational Language: has no direct link to readability, but is often used with the goal of convincing readers of the importance of the work. There is clearly some merit to this strategy, as sensational language used in the abstracts has been linked to increased citations (Boutron et al., 2014; Millar et al., 2022). However, an over-reliance on sensationalism can result in over-hyping and spin (Mammola, 2020; Millar et al., 2022). We broke this language into nine categories:

- Importance—words emphasising significance (e.g. compelling, essential, paramount)
- Novelty—words emphasising originality (e.g. emerging, revolutionary, unprecedented)
- Rigour—words emphasising methodological quality (e.g. cohesive, robust, systematic)
- Scale—words emphasising breadth/depth (e.g. comprehensive, immense, overwhelming)
- Utility—words emphasising practicality (e.g. actionable, productive, sustainable)
- Quality—words emphasising personal credentials (e.g. dedicated, prestigious, renowned)
- Attitude—words emphasising subjective perspectives (e.g. exciting, incredible, remarkable)
- Problem—words emphasising the problem (e.g. daunting, dire, elusive)
- Additional—words not included in the original Millar, Batalo & Budgell study (e.g. backbone, extreme, decisive).

These categories were based on a previous study by researchers Millar et al. (2022) and covered as a key concern by The Lancet (Bauchner & Rivara, 2022).

We also analysed the variation in writing components between different countries to see if there were any significant regional differences in scientific writing style.

Results

We detected several significant changes in the ways scientific papers are being written. In fact, the only area we found that was broadly stable was the use of signposting — with the exception of a significant dip in the late 1960s (Fig. 2).

A three by three grid of line graphs. Each of the graphs shows a range of years on the x-axis, on a scale from 1950 to 2022. The y-axes display the frequency of the writing component of interest per 100 words. The top-left graph shows the use of signposting, which is

roughly the same in 2022 as it was in 1950. The top-middle graph shows the use of hedging, which has decreased since 1950. The top-right graph shows the use of noun chunks, which has increased since 1950. The middleleft graph shows the use of active narration, which has increased since the 1950s. This graph is different from the others as the y-axis displays the percentage of abstracts this component appeared in, rather than the frequency of this component per 100 words. The middle-middle graph shows the number of words per sentence, which has decreased since the 1950s. The middle-left graph shows the use of sensational language, which has increased since the 1950s. The bottom-right graph shows the use of verbs, which has increased since the 1950s. The bottom-middle graph shows the use of nouns, which has increased since the 1950s. The bottom-left graph shows the use of numbers, which has increased since the 1950s.

On the positive side of things, we found a decrease in hedging words and an increase in active narration (Fig. 2). These changes impart a sense of "action", thereby increasing reader engagement. The use of hedging has rapidly and steadily decreased since the 1950s. This is seen across all forms of writing. In addition, the use of active narration

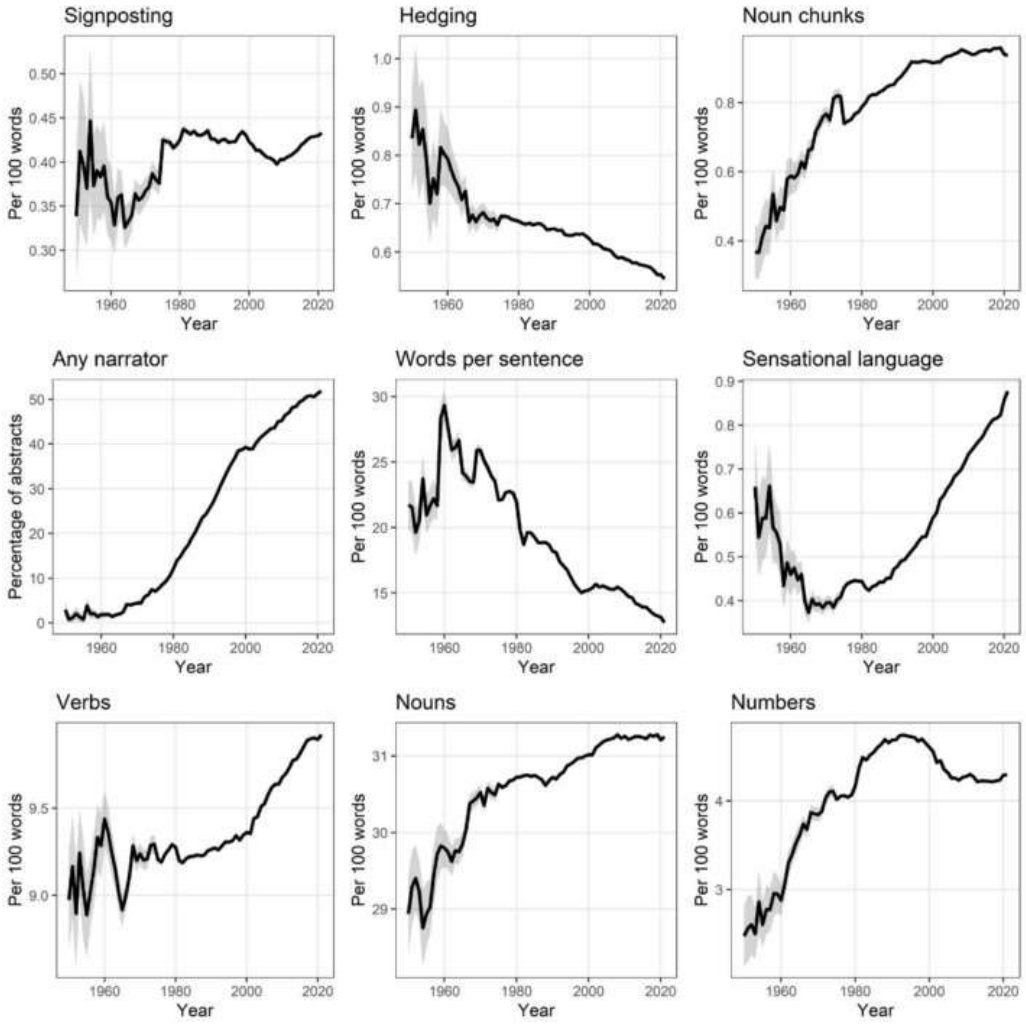

Fig. 2 The annual trends in the use of various writing components used in abstracts over time. Results displayed as an average per 100 words, expect for "Any narrator" which is a binary Yes/No outcome

(papers that use first-person language) has increased since the 1950s. This trend is stable across most forms of writing. This indicates that researchers are putting some effort into writing in a more reader-friendly manner.

Another positive change is the average number of words used per sentence. This trend peaked in the 1960s and has decreased greatly since then—dropping from an average of 29 to less than 15 (Fig. 2). This decrease is primarily driven by underlying decreases in word count per sentence in case reports, clinical trials, and journal articles. Such changes are hypothesised to reduce cognitive load and increase the readability of articles.

In contrast, there are a few areas where modern writing practices have declined in quality since the 1950s. Most notably, the use of noun chunks has increased greatly since the 1950s (Fig. 2). "Noun chunks" are where three or more nouns are used in a row. Noun chunks are thought to have a negative effect on cognitive load experienced by the reader. Such load can also be increased by an over-reliance on numbers. We found that the use of numbers has greatly increased since 1950, peaking in the 1990s before stabilising in the mid-2000s (Fig. 2). Clinical trials were much more likely than other writing forms to use numbers.

We also detected trends that have no direct beneficial or detrimental effects. For example, the use of nouns has increased since the 1950s, from 29 to 31 per 100 words (Fig. 2).

The use of verbs has increased since the 1980s and this increase has grown rapidly since the 2000s (Fig. 2). This trend is variable between different types of writing and is most clear in journal articles and case reports. The use of verbs is also the only variable where we found a significant difference between countries, with primarily English-speaking countries (Australia, Canada, the United Kingdom, and the United States) being more likely to use verbs compared to other countries (Fig. 3). However, the overall direction of the trends was similar regardless of country. Whilst the exact increase of 9 to 11 verbs per 100 words may not be meaningful per se, it does suggest that writers are increasing keen to create engagement, imagery, and narrative flow.

A line graph. Years are displayed on the x-axis, ranging from 1950 to 2022. The y-axis displays the frequency of verbs per 100 words. The graph has several lines of different colours, each of which represent a different country (Australia, Canada, China, France, Germany, Italy, Japan, United Kingdom, United States, and 'Missing Information'. All of the lines show an increase in the use of verbs since the 1980s. However, the trend lines representing Australia, Canada, the United Kingdom, and the United States are clustered further up the y-axis compared to the other countries.

Another factor that can increase reader engagement is the use of sensational language, though sensationalism can also lead to inaccuracy. In each of the categories examining sensational language we found an increase in use-cases since the 1950s. The strength of this increase varies greatly between categories (Figs. 2 and 4).

A line graph. Years are displayed on the x-axis, ranging from 1950 to 2022. The y-axis displays the frequency of sensationalistic words per 100 words. The graph has several lines of different colours, each of which represent a different category of sensational language. The use of importance words is shown in grey and has increased since the 1980s. The use of novelty words is shown in orange and has increased since the 1950s. The use of rigor words is shown in blue and has increased since the 1980s. The use of scale words is shown in green and has increased slightly since the 1980s. The use of utility words is shown in yellow and has increased since the 1980s. The use of quality words is shown in dark blue and as increased slightly since the 1980s. The use of attitude words is shown in red and has increased slightly since the 1960s. The use of problem words is shown in pink and has

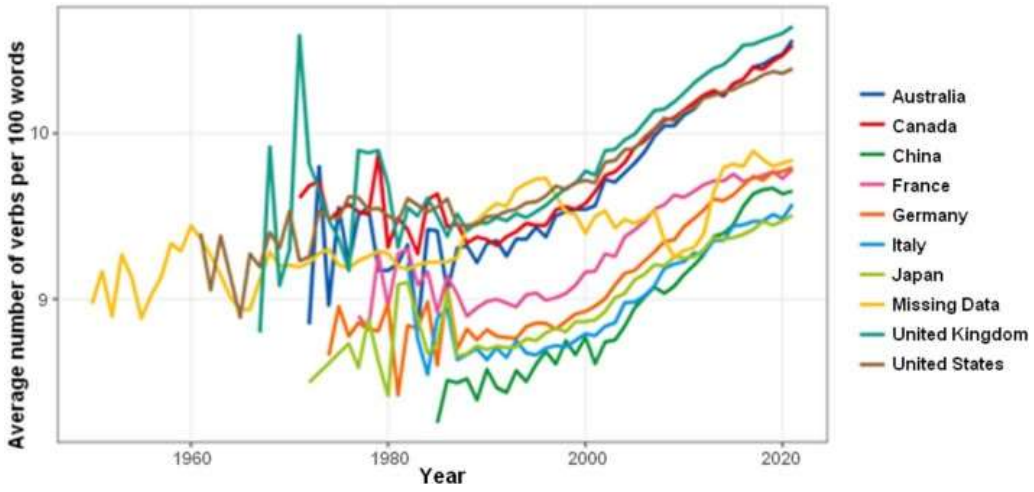

Fig. 3 The annual trends in the average number of verbs used per 100 words over time. Different lines represent different countries

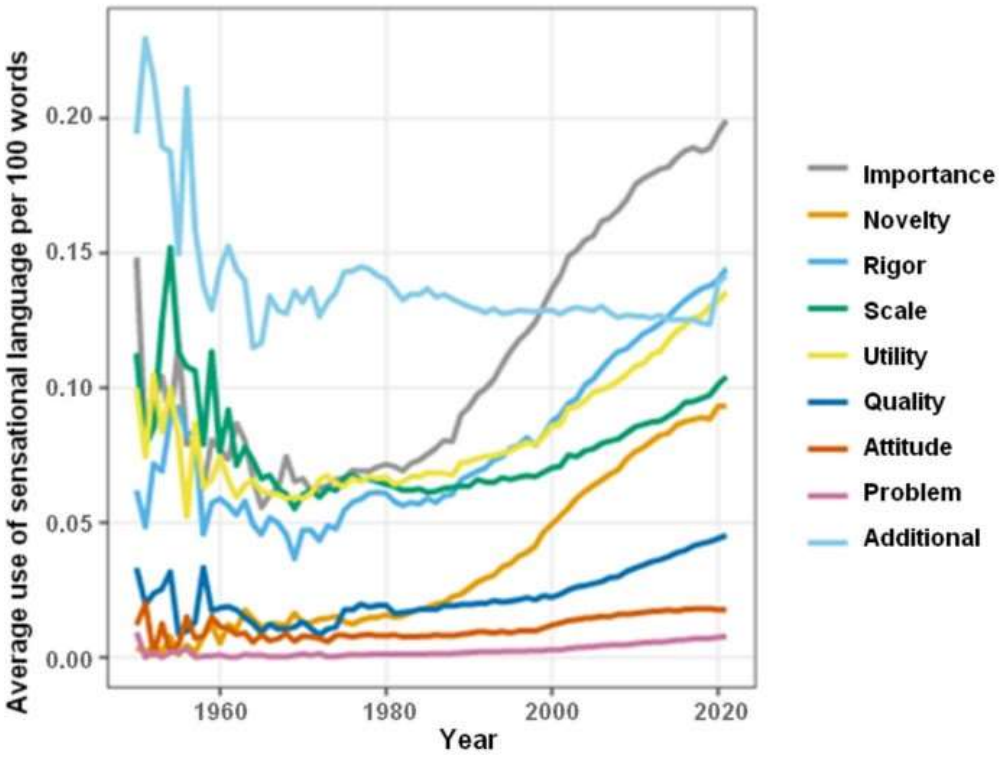

Fig. 4 The annual trends in the average number of sensationalistic words used per 100 words over time. Different lines indicate the different categories of these kinds of words (Millar et al., 2022)

increased slightly since the 1950s. The use of additional words is shown in light blue and has decreased slightly since the 1950s.

Discussion

There is a clear need for accessible writing in peer-reviewed articles. Papers are more likely to be cited when they are written in a more understandable way (Martínez & Mammola, 2021; Sawyer et al., 2008; Vergoulis et al., 2019). Clear writing can also assist the process of interdisciplinary communication and collaboration and allow non-scientists to gain an understanding of the processes and outcomes of scientific investigations. In contrast, unclear writing can reduce the ability of readers to understand and recollect the information (Ayres, 2006; Britton et al., 1982; Wang et al., 2020). This is true even for experts in the field, as prior studies have found that miscommunication is a prevalent issue in scientific journals (Lei & Yan, 2016; Todd et al., 2010).

Scientific writing practices have changed over time (Barnett & Doubleday, 2020; Millar et al., 2022). It is worth considering if scientific writing has changed in a way that helps or hinders readers in understanding a paper. Components of writing which have been examined by other researchers in the past due to their ability to support understanding in readers include: noun chunks, sign-posting, active narration, hedging words (Freeling et al., 2021; Ryba et al., 2019), short sentences (Begeny & Greene, 2013), sensational language (Mammola, 2020; Vinkers et al., 2015), active verbs (Coleman & Blumenfeld, 1963), and the undue use of numbers (Miller, 2004).

Through our analysis of millions of scientific papers, we found several types of writing components that improve readability have been increasingly used. The changes that improved readability were: the increased use of verbs and active narration, and the decrease in hedging statements.

We hypothesise that these three changes work to reduce the cognitive load of a paper, making the reading process more understandable and therefore engaging. The increase in active narration helps to engage the reader with the work by adding a sense of immediacy and involvement, reduces the prevalence of passive voice, and increases clarity by clearly designating cause-and-effect relationships. Verbs also increase audience engagement by imparting a sense of action into a piece. In contrast, high amounts of hedging can reduce engagement in a paper — as these words "weaken" the perceived impacts, introduce ambiguity, and undermine authority (Hillier et al., 2016; Montgomery, 2003; Yao et al., 2023). However, it is important to recognise that in some cases hedging is important for acknowledging areas where genuine ambiguity exists (Hoekstra & Vazire, 2021).

There are some areas where modern writing practices have a negative impact on readability. Namely, the use of "noun chunks" — where three or more nouns are used in a row, e.g. computer software systems — has increased over time. Readers often consider the digestion of noun chunks to be difficult, possibly as a result of an increase in cognitive load. If true, such load reduce a reader's capacity to understand the central message (e.g. Freeling et al., 2021) and relate ideas to one another. Where cognitive load is sufficiently heavy, it is not difficult to assume that readers could become bored and "switch off" from properly striving to understand and retain the writers' key messages.

Concerningly, the use of sensational language has increased over the last 40 years. We examined several categories of sensational language (Millar et al., 2022) and found this trend was most noticeable where authors used words that stress significance, priority, and

urgency (e.g. key, paramount, pressing) (Millar et al., 2022). Sensational language is often used by authors in order to attract readers by stressing the importance of their research. In some cases, truly ground-breaking research warrants sensationalism. But in other cases, sensational language is used to "over-hype" research, stressing its importance to an inaccurate degree (Mammola, 2020; Millar et al., 2022). Sensationalism can change the way readers interpret a paper and give them misleading impressions about the results.

As time passes, it seems that scientists are putting increasing effort into improving their writing; as shown by the increase in the use of active narration and verbs, and the decrease in hedging statements. But there are other places where writers still feel a need adhere to 'The Official Style' and where they fall back on dense prose such as noun chunks and an over-reliance on numbers (Doubleday & Connell, 2017; Lanham, 1979). It is not difficult to imagine that such writing creates cognitive drain for readers.

It is important to note that including a few basic writing components does not, by itself, make writing clear. True clarity also depends on connecting key ideas in a logical way and ensuring that technical terms are properly defined. Therefore, there are other important elements to writing clarity which we did not explore in this study. Regardless, we believe the results can offer useful insights into some of the important writing components that researchers can easily integrate into their work.

Of course, we cannot be certain what exactly is driving the changes detected in this study. However, we can make a few suggestions as to their origins. They could, of course, be the result of active decisions on the part of the writers. The increased use of personal language could be linked to changes in editorial guidelines. While traditional writing guidelines frowned upon first-person narration in scientific texts, this style is becoming increasingly accepted over time. This conclusion is supported by the fact that in certain areas the data gathered shows gradual changes over time when viewed as a whole, but shows clear "jumps" in writing style at the level of individual journals. For example, the journal *Nature* showed a large increase in the number of writers using first-person language in the abstracts of journal articles in the 1980s — which be a result of changing editorial practices (Fig. 5).

A line graph. Years are displayed on the x-axis, ranging from just before 1970 to 2022. The y-axis displays the percentage of abstracts in the journal Nature that use active narration. The use of active narration is slowly increasing from 0 to 20% until just before 1980, when it suddenly jumps to being used in around 70% of abstracts. Since then, the trend has continued to increase at a slower rate until reaching 100% in 2022.

Changes in writing style over time could also be the result of a self-perpetuating system. If scientists read a lot of articles, they may mimic the styles they read. This change could be conscious, with authors intentionally writing in ways that match the style of published papers which they consider to be successful at conveying a message (Hodges & Narum, 2015). But the writing style researchers use could also be unconscious, as authors subconsciously write in similar ways to articles they have read and enjoyed, or may believe that copying this style will increase their chance of publication. As a result of these patterns of mimicry, certain types of writing become culturally accepted over time and breaking away from these styles becomes increasingly difficult.

This trend becomes even more significant when one considers the role that academic supervisors — who have many years of experience and expertise — have when it comes to providing feedback to their students' and shaping their scientific voices. Academic mentors are likely to teach their students to write in the way they themselves write (Negretti et al., 2022). As their students are likely to go into the same field of research, this means that over time a particular "in-house" writing style can become

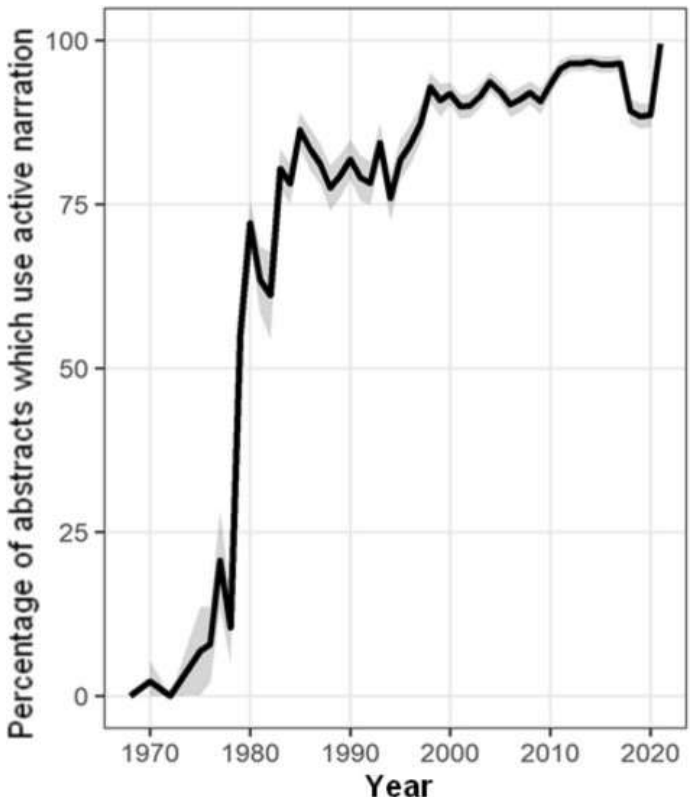

Fig. 5 The percentage of abstracts of journal articles from the scientific journal Nature that use active narration over time. The use of active narration was calculated as a binary yes or no outcome, whereas the other outcomes are counts

prevalent within that academic field. While this can allow for shared understanding between researchers and the continuation of established norms within fields, this can also hinder interdisciplinary communication between different fields. These unmoving norms can also make it difficult for new perspectives on writing to be heard, resulting in entrenched writing practices.

It is also important to keep in mind the effect that university and institutional guidelines have on writing style. Researchers are commonly expected to publish "important" and high-impact articles — and in some cases this is even a requirement of their role. This could lead to overhyping research; shown in this study by the reduction in hedging and converse increase in sensational language (Jawaid, 2016). Researchers are encouraged to ensure that their research is seen in the most impactful light possible, especially if they wish to receive funding. This pressure can also create a survivorship bias where researchers who write in sensational ways are more likely to see future success in their field — and therefore have more influence to shape the styles of writing used in their field (Bornmann, 2010). We emphasise that succumbing to this pressure is unlikely to lead to good scholarship (Doubleday & Connell, 2017).

Our analysis of the evolution of scientific writing may serve a prompt for other researchers to explore these trends and their validity in other disciplines. We suggest that such future work would benefit by considering three approaches. First, a more refined design of a comprehensive metric that assigns these components varying weights (see Hou & Smith, 2021). This metric could be employed to directly test changes in cognitive load. Second, the experimental use of word embedding that transforms words that have been selected for their specific component, potentially enabling multivariate comparisons that go beyond univariate counts of frequencies. Third, use a combination of techniques (including above)

and research domains (e.g. physics, biology, computer science) to not only validate the findings, but to establish a broader perspective and limits to generality.

Conclusion

We reveal shifts in scientific writing over the last 70 years. On the positive side, the use of verbs and active narration has increased, and the use of hedging language has decreased. But there are still many areas where the clarity of writing can be improved — most notably a worrying increase of noun chunks. There are many possible explanations for these changing trends. It seems likely that scientific fields will adopt similar writing styles over time. As scientists read successful papers, they may try to mimic the writing style found within this paper. Over time, this results in an insular community dominated by mimicry of style.

We advocate for more accessible prose, such that this democratisation of knowledge enables a wider spread of knowledge across the science and non-science populations, not just specialists. The modern world is increasingly connected and people — both scientists and laypeople — have greater access to research than ever before. Ideally, this would allow for the democratisation of knowledge across society and the continued progress of science as an interdisciplinary field driven by peer-to-peer communication. But the benefits of the internet age for science are limited if our work remains inaccessible behind a linguistic wall. It is valuable for researchers to pay attention to the ways in which papers are written. In doing so, they can ensure their intended message rings clear for readers.

Appendix I—Justification of methodology

There are multiple methods that prior researchers have used to estimate the readability of scientific texts. One of the most common is readability matrices (Graf-Vlachy, 2021; Jeong et al., 2021; Plavén-Sigray et al., 2017). These are tools that attempt to algorithmically define how readable a given text is. They have the benefit of being quick and easy to apply, and require no subjective analysis on the part of the researcher. As a result, they are very common in communication research.

Readability matrices have the potential to be applied to large samples due to their simplicity, but their simplicity is also a weakness when it comes to gauging the clarity of an article. It is possible that the overall structure of a paper either increases or reduces clarity in a way that readability matrices cannot detect (Dolnicar & Chapple, 2015; Redish, 2000). For example, a sentence that contains an example would be marked as worse than a sentence *without* an example by many common readability matrices, purely because the former sentence is longer. To offer another example, the preceding sentence uses the term "the former sentence" rather than "it" to ensure that the syntax is clear. In addition, readability matrices cannot detect logical writing. A nonsense sentence that is short and uses simple words (e.g. "Sat mat the on cat the") would receive an excellent grade when run through a readability matrix (see Table 1).

Some studies have found only a weak association between the conclusions reached by these formulas and reading comprehension — both among adult and child readers (Begeny & Greene, 2013; Crossley et al., 2017). There are other studies which dispute this finding (DuBay, 2004; Graf-Vlachy, 2021; Jeong et al., 2021). But the presence of a debate indicates that these methods should not be considered overly reliable. None

Table 1 There are many different readability matrices that have seen widespread use. While they often share similarities; they examine slightly different things, and/or use different equations to calculate readability. Here are some examples of common matrices, and the aspects of texts that they examine (Begeny & Greene, 2013)

Readability matrix	Aspects of the text examined
Dale-Chall Readability Matrix	Percentage of difficult words, i.e. words *not* on a list of 763–3000 "common" words (the exact number is dependent on the version of the matrix used), and the average number of words per sentence
Flesch-Kincaid Grade Level	Average number of words per sentence, and the average number of syllables per word
FORCAST Formula	The average number of single-syllable words per 150 words
Fry Readability Formula	Average number of sentences and syllables per 100 words
Gunning Fog Index	Average number of words per sentence, and percentage of words with three or more syllables per sentence
Lexile Framework	Average number of words per sentence, and how "common" the language used is
Powers Sumner Kearl Readability Formula	Average number of words per sentence, and number of syllables
Simple Measure of Gobbledygook	Average number of words with three or more syllables per sentence
Spache Readability Formula	Average number of words per sentence, and percentage of "uncommon" words (i.e. words *not* on a list of "common" words)

of this is intended to diminish the role that readability formulas can play in research. As previously stated, their simplicity means they can easily be applied to large samples. However, their flaws mean they cannot be considered the be-all and end-all when it comes to judging readability

Another method of testing readability is "usability testing", in which readers are brought in to assess the texts directly (Hartley, 2000). These readers can then be asked to give feedback on how well they understood the message/s of the text, and even be tested for knowledge retention. While this form of feedback is very useful, and offers probably the best insight into readability, it is not always practical for researchers to use this method — especially in meta-research. The need for readers greatly increases the budget and difficulty associated with the research and reduces the sample size than can feasibly be gathered. It also has the downside of being subjective, rather than the objective conclusions offered by readability formulas

Usability testing can either be "reader-based" or "expert-based". The former relies on laypeople or other non-experts, while the latter uses people within the field to assess the accessibility of the paper (Hartley, 2000). Of course, both methods still have the issue of requiring increased budget and time, and necessarily reducing sample-size

Other research strikes a balance between the simplicity of readability matrices and the complexity of usability testing, by tracking the presence of certain kinds of writing components that can help to further understanding in a reader. For example:

- Ryba, Doubleday and Connell tie readability to several text components; including the use of explicit settings, consistent language between sentences, and the use of hedging terms (Ryba et al., 2019).

- Martínez & Mammola judged readability based on "jargon" — as defined based on the glossaries of a number of scientific texts (Martínez & Mammola, 2021).
- Stremersch, Verniers & Verhoef used the Flesch Reading Ease Matrix to judge readability, in *addition* to the presence of equations, figures, tables, footnotes and appendices (Stremersch et al., 2007).
- Sand-Jensen suggests ten components that can increase audience engagement: clear focus, originality/personality, short contributions, including implication and speculation, illustrations, having clear reasoning, using few abbreviations, using humour, not relying overly on statistics, and keeping quotations to important areas only (Sand-Jensen, 2007).
- Britton et al. found that texts containing signals about idea importance and idea relations required less cognitive capacity to process than texts with approximately the same propositional content (Britton et al., 1982).
- Hillier, Kelly & Klinger used a number of writing components to gauge the narrativity of a paper, which they had previously linked to increased knowledge retention. They examined papers for: setting, narrative perspective, sensory language, conjunctions, connectivity, and appeal (Hillier et al., 2016).

For this study, we decided to use Hiller, Kelly, and Klinger's method. This allowed us to obtain a sample size in the millions, without relying solely on word-choice and/or sentence length. Instead, we examined nine different writing components to see how they have changed over time. Namely, we examined:

- Sensational Language (Millar et al., 2022).
- Sentence Length (Britton et al., 1982; Jeong et al., 2021).
- Sign-Posting (Lindsay, 2011; Montgomery, 2003).
- Hedging (Montgomery, 2003; Pinker, 2014; Sword, 2012).
- Noun Chunks (Lindsay, 2011; Montgomery, 2003; Pinker, 2014).
- Active Narration (Hillier et al., 2016; Pinker, 2014; Sword, 2012).
- Verbs (Hillier et al., 2016; Ryba et al., 2019).
- Nouns (Crossley et al., 2017).
- Numbers (Stremersch et al., 2007).

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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Chapter 3: Clear writing reduces cognitive load and enhances reader engagement

Abstract

It is generally agreed that being able to write scientifically in a way which conveys ideas quickly and accurately is a key skill for researchers working today. Despite this, modern scientific writing still tends towards highly technical and detailed wording which can make the writing less understandable. We tested the impact of writing style on reader recall and engagement. We wrote two scientific abstracts, one of which utilised several writing techniques associated with improving readability and one which did not. The abstract which used these techniques was strongly linked to improved recall on the part of the reader. In addition, readers consistently self-reported a preference for abstracts written using these techniques. The results of our analysis indicate that abstracts intentionally written with an eye for clarity could boost reader understanding and engagement. When reading an abstract written with a focus on writing clarity, readers feel far more engaged with the text and better recall its contents. Not only that, but readers have more positive subjective feelings about the text as a whole. This suggests that there are benefits for researchers who take the time to write in reader-friendly ways.

Introduction

In the modern world, science has the potential to become more freely available to everyone with access to the internet (Bowman & Bozich 2015). The widespread establishment of public education systems has given more people the knowledge needed to engage – at least on a basic level – with the world of academia. In addition, the continued growth of mass media communication and open access publishing has made scientific papers more accessible than ever before. One example of this is the implementation by Google of an artificial intelligence that summarises complex topics within the search function by pulling from texts published online. Despite this, scientific writing is often characterised by a rigid structure, dense prose, and a heavy reliance on jargon which does not facilitate reader understanding. Often, scientists are not expected to write in compelling ways, nor are they taught these skills during their training (Glew, Challa & Gopalan 2014; Ritchie et al. 2022).

This problem is so pronounced that scientists can even struggle to understand papers from within their own field. For example, up to a quarter of papers referenced in the field of marine biology offer unclear support for the relevant assertion. Some of this inaccuracy may well be the result of deliberate misrepresentation, but it is also likely that at least some of this discrepancy is the result of honest error (Todd et al. 2010). If scientists can so readily make errors in comprehending a paper,

the increased access to scientific information by the general public is likely to lead to even greater misunderstanding and misinformation, potentially evidenced by the increased prevalence of anti-scientific movements such as anti-vaccine and climate change denial in the modern world (Seymour et al. 2015).

This gap in understanding may be partially due to the usual, dense style of scientific writing which places undue mental burden on the reader (Sweller, van Merrienboer & Paas 1988). However, writers can attempt to reduce the mental burden associated with their writing and in doing so make it easier for people to understand their key messages. By moving away from more complex styles of writing, writers can minimise the mental burden of their writing without necessarily sacrificing detail or nuance (Britton et al. 1982; Jeong, Rogers & Washispack 2021; Sweller 1994). The potential burden of reading can be reduced by using writing features such as minimal jargon, an active voice, short sentences, and minimal acronyms (Narod, Ahmed & Akbari 2016; Li et al. 2018; Sweller 1994; Wang, Fang & Gu 2020). While clarity can be obtained by presenting information in a logical order and using precise language, texts can be also be made more engaging and memorable to readers by using creative and inspiring language (Doubleday & Connell 2017; Ryba et al. 2021). This not only benefits the reader, but can also benefit the writer, as clear writing can play a role in the citation frequency of a paper (Sawyer, Laran & Xu 2008; Vergoulis et al. 2019; Martínez & Mammola 2021). Clear writing can also have a positive impact on the readers' capacity to understand the information presented in a scientific text, which in turn supports recall ability (Ayres 2006; Sweller 1994; Wang, Fang & Gu 2020).

When engaging with a scientific paper, most people will start by reading the abstract (Pain 2016; Rutkowski 2020). This provides an opportunity for researchers to "hook" their readers and to communicate their key ideas in a concise and accessible way. In addition, the readability of an abstract is often reflective of the readability of the paper as a whole (Plavén-Sigray et al. 2017). This means that examining abstracts can be useful when it comes to examining scientific writing and the impact that writing styles can have upon readers.

There are several different techniques people have used to try and measure mental burden such as directly surveying readers (Ryba et al. 2021) or using mathematical models known as "readability matrices" (DuBay 2004). However, debate still continues as to which of these methods is most effective for understanding the impact of different writing styles. In this paper, we aim to explore the idea that specific writing features can be linked to mental burden on the part of the reader. These features can impact reader understanding, recall, and engagement with a scientific

text. We predict that we will see an overall increase in recall and more positive feedback after reading an easy-to-follow abstract (which uses features associated with improved clarity) as opposed to a densely worded abstract (which uses features associated with reduced clarity).

Methods

We recruited the participants (n = 22) for our study over the latter half of 2024. The majority of our participants were students currently enrolled at the University of Adelaide, though some were members of the public recruited through social media. Ethics approval was provided by the University of Adelaide School of Psychology (Approval Number: 23/89).

An electroencephalograph (EEG) was used to measure the brain activity of our participants throughout the process of conducting this experiment. The results of these tests are still preliminary and are part of a boarder collaboration. These results are reported in more detail in Appendix I.

Each of our subjects were tested individually. First, we set up the EEG and verbally explained the general process of the experiment to our subjects. We then started our EEG recording via the BrainVision Recorder software and left the room. Subsequent instructions and the subsequent abstracts were presented to the subjects on a computer monitor, which they were able to progress manually by pressing the spacebar.

The experiment started with a period of calibration in order to obtain baseline readings of brain activity. Subjects were asked to stare a fixed position for 2 minutes, then close their eyes for 2 minutes. The subject was then presented with either an easy or hard abstract, with the order alternating for each subject (see Appendix II). These abstracts were based on ones previously used in a paper by researchers Ryba et al. (Ryba et al. 2021). The harder abstract included a greater number of writing features known to increase mental burden. These included:

- Acronyms: An over-reliance on acronyms can be confusing for readers unless the general meaning of said acronyms is already well-known (e.g. DNA, MRI). Otherwise, acronyms can increase mental burden by forcing the reader to commit the stated definition to memory (Narod, Ahmed & Akbari 2016).
- Long Paragraphs: Long, unbroken sections of text are known to increase mental burden. While the two abstracts we used here had equivalent word-counts, the harder abstract used longer sentences and lacked paragraph breaks. This presentation increases mental burden due to the lack of conciseness (Katzoff 1964).

- Impersonal Language: Impersonal language and the passive voice are known to reduce reader engagement with a text. In contrast, personal language (e.g. I, we) increases the narrative style of a piece of writing, which in turn increases audience engagement (Li et al. 2018).
- Jargon: In limited quantities, jargon can be very useful for scientific communication as it is able to distil complex topics into a few words. However, jargon can also render abstracts impenetrable to non-experts, especially when it is undefined (Bullock et al. 2019).
- Lack of Connectivity: One of the most important elements of scientific writing is conjunctions and other linking words that can be used to illustrate how certain ideas fit together. If these are not used appropriately, the text can make logical leaps which increases mental burden on the reader (Pinker 2014).

Both abstracts contained the similar information with the same basic facts and focused on the same topic. They differed only in the writing style used to convey said information (detailed above). The abstract which was presented first alternated for each subject. Subjects were given as long as they wanted to read the abstract to account for natural variations in reading speed. The subjects were then presented with a one-back working memory test followed by a two-back working memory test to act as a distraction task. The length of this task varied based on the response speed of the subject (no maximum time was given) but generally lasted around 20-30 minutes.

Following the distraction tasks, a researcher re-entered the room and asked the subject to narratively recall the abstract in as much detail as they could remember. Narrative recalls were rated against 12 key points from each abstract. Eleven of these 12 key points were consistent across the two versions of the abstract. Following the free recall, predetermined prompt questions were asked for any of the 12 key points the subject had missed. Three points were allocated for each key point the subjects missed but were able to recall without prompting. Two points were allocated for every key point the subject recalled after we gave them a simple prompt. One point was allocated for every key point the subjects completely failed to recall (see Appendix III). Subjects were not provided with their score.

Following the narrative recall task, the subjects verbally reported their enjoyment of the abstract, their confidence in their understanding, the amount of mental energy they spent in reading, and how easy they thought the abstract was to understand on a 1-5 Likert Scale. These scales are detailed here:

- On a scale from 1-5 (with 5 being the easiest), how easy was the abstract to understand?
- On a scale from 1-5 (with 5 being the most confident), how confident are you that you understood?
- On a scale from 1-5 (with 5 being the most), how much did you enjoy the abstract?
- On a scale from 1-5 (with 5 being the hardest), how hard did you need to work mentally?

The researcher then then left the room and the subject was presented with the alternate version of the abstract, using the same computer monitor as the rest of the experiment. We alternated the order in which the abstracts were presented for each subject in an attempt to control the effect of the repeated information across the sample.

After reading the second abstract, the subject was again given the one-back and two-back task as a distraction, followed by the narrative recall task as described above and the Likert scale questions. Finally, subjects were asked demographic questions so we could control for these variables during our analysis. These questions were: dominant hand (as this can impact the EEG readings), level of education, area of education, first language, gender, and ethnicity. Figure 1 shows the experimental design.

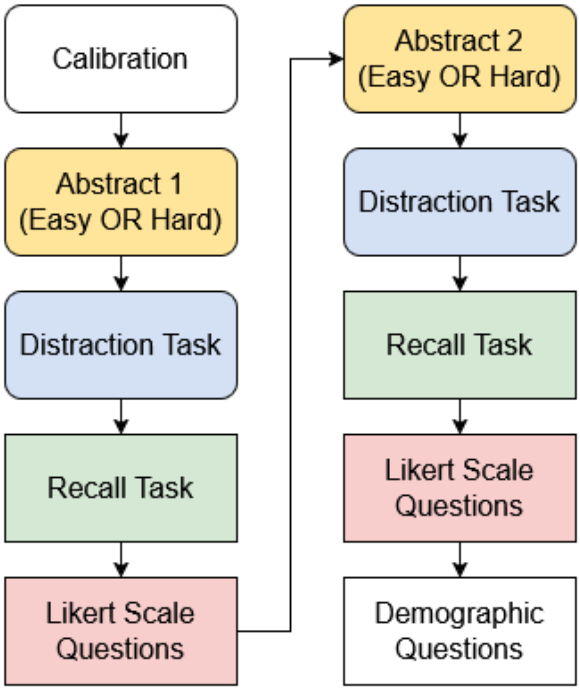

Figure 1. *A protocol diagram for the test administered to subjects. Boxes with rounded edges indicate a process administered automatically as the subject manually progressed through the instructions presented on the computer monitor. Boxes with sharp edges indicate a process administered verbally by a researcher.*

We compared the mean and standard deviation of the results of the recall test and opinion polls using one-way ANOVA testing in RStudio version 4.4.2 (R Core Team 2022).

Results

From our one-way ANOVA analysis of the recall scores, we found that people were more able to recall the abstracts which were written using easy to understand language. The easy abstract resulted in an average recall score of 26.82 ±3.65 compared to 22.82 ±3.99. This difference was significant at $p < 0.01$ ($n = 22$, $F_{1, 42} = 12.03$, $\eta^2 = 0.22$; see Figure 2 for a comparison of the results).

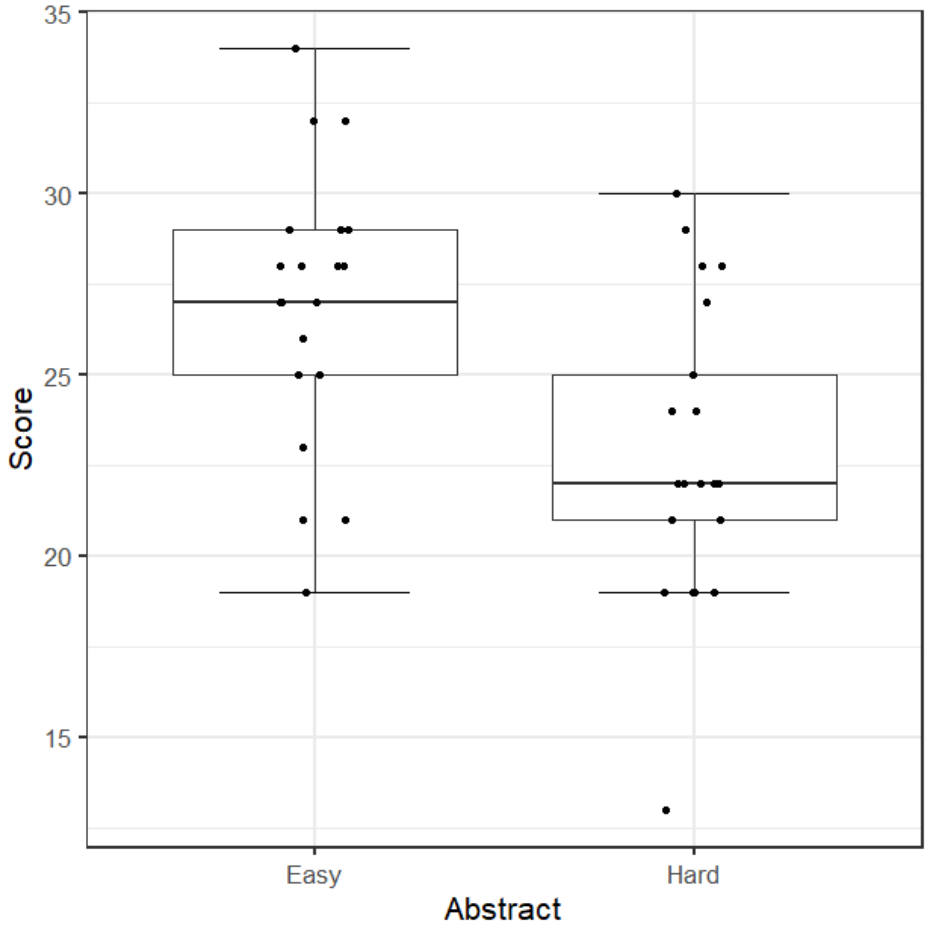

Figure 2. *Boxplot of the results of the recall test, comparing the easy abstract versus the hard abstract. The average score for the easy abstract was 26.82, compared to the hard abstract average score of 22.82. This difference was significant (p <0.01).*

In addition, the subjects had self-reported more positive emotions associated with the easier abstract in all four categories we analysed. Subjects reported that the easy abstract was easier to read, were more confident in their understanding, enjoyed the abstract more, and found it required less mental effort. All four of these Likert results were significantly different between the two abstracts, as was confirmed through one-way ANOVA testing of all four categories where p was <0.01. More specifically:

- Ease of Reading: $n = 22$, $F_{1, 42} = 68.34$, $p < 0.01$, $\eta^2 = 0.62$
- Confidence: $n = 22$, $F_{1, 42} = 28.32$, $p < 0.01$, $\eta^2 = 0.40$
- Enjoyment: $n = 22$, $F_{1, 42} = 38.70$, $p < 0.01$, $\eta^2 = 0.48$
- Mental Effort: $n = 22$, $F_{1, 42} = 37.42$, $p < 0.01$, $\eta^2 = 0.47$

See Figure 3 for more information as to the distribution of the responses.

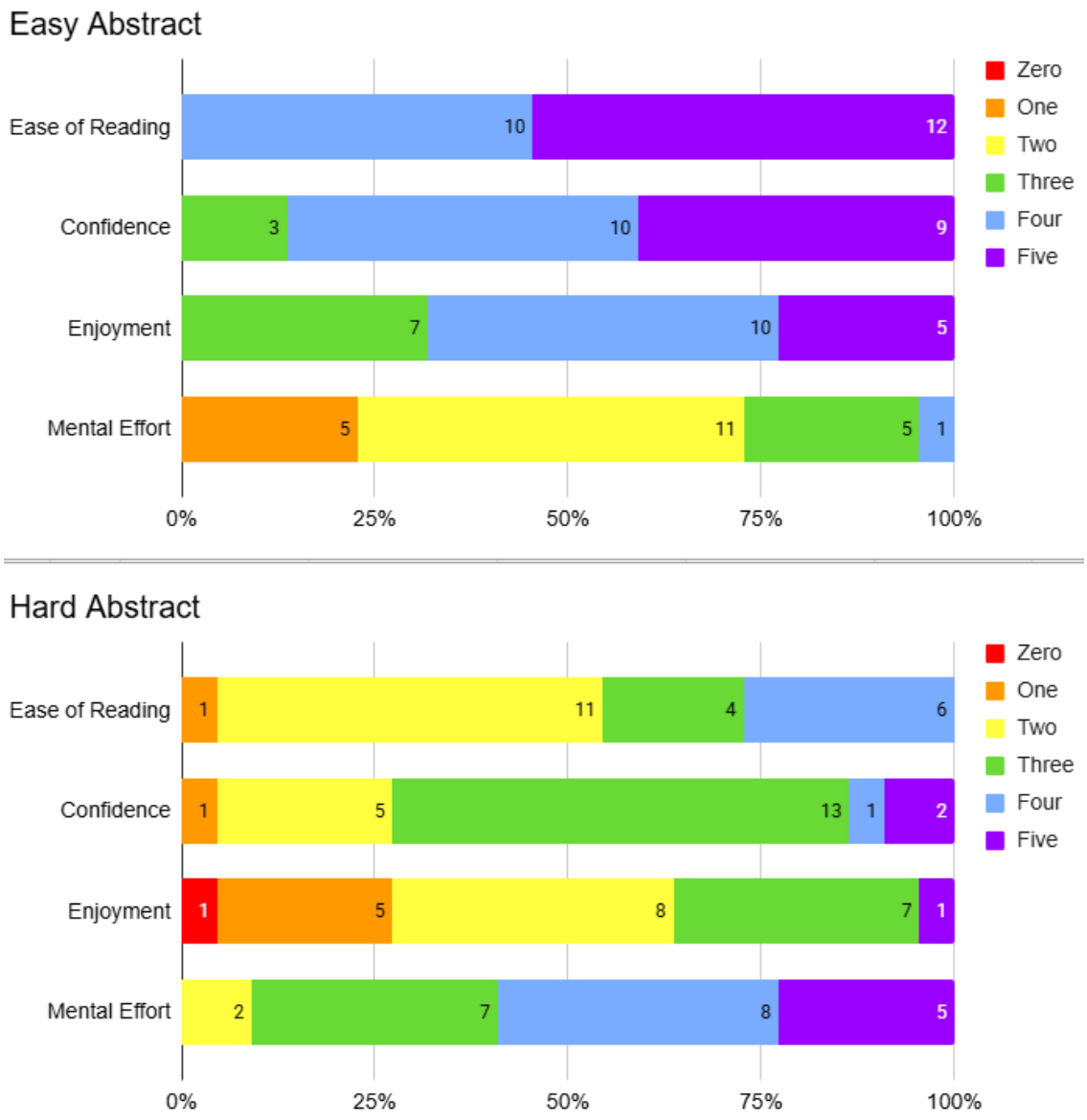

Figure 3. *Results of self-reported reading experiences presented as a Likert chart. The variables presented here are the results for the ease of reading, confidence in understanding, enjoyment, and mental effort associated with reading the abstract (each rated on a scale from 0-5). Red indicates the percentage of respondents (per category) who gave the abstract a score of zero, orange a score of one, yellow two, green three, blue four, and purple five. The upper graph shows the results for the "easy" abstract while the lower shows the results from the "hard" abstract. In cases where the respondent gave a decimal answer (e.g. 2.5), these scores were rounded up.*

It is important to note that subjects may have found the second abstract easier to recall due to the topic being the same as the first. We made the decisions to keep the topic consistent to minimise variation between the two abstracts (in terms of topic and content). Regardless, we conducted one-way ANOVA testing to explore these potential effects.

We found that there was no significant relationship between the score people obtained for the easy abstract and the abstract they read first ($F_{1, 20} = 2.58$, $p = 0.12$, $\eta^2 = 0.11$). However, people who read the hard abstract first received an average score on the "hard" recall test of 25.30 ±3.62, compared to people who received it second, who received an average score of 20.75 ±3.08 ($F_{1, 20} = 10.16$, $p = <0.01$, $\eta^2 = 0.34$).

The results of the EEG test were less straightforward and as such further study is required to fully understand the relationship between writing style and brain activity. Hence, our preliminary results are reported in Appendix I. In addition, a brief discussion of demographic factors is included in Appendix IV.

Discussion

Science is a process of collaboration with fellow researchers and outreach to members of the public. Journal articles are written for the purpose of sharing ideas; therefore, the process of writing in an understandable way is an important skill for modern researchers to focus on (Abraham 2020). In addition to the theoretical benefits to society that comes from a focus on clear writing, scientists may also experience some direct benefits from focusing on their writing skills. For example, there is evidence to suggest that clear writing may be linked to an increase in citations. An article written in an easily understood style allows researchers to quickly draw connections between the key findings of a study and their own work, increasing the chances of it being cited (Hohmann & Connell 2025; Sawyer, Laran & Xu 2008; Martínez & Mammola 2021). In contrast, if science is not written about in an understandable way, no-one will be able to engage with the underlying concepts (Dunnwald, DeLeon & Burrows 2025).

In this study, we found other benefits to writing in a way that is easily understood by readers. We found that a clear, understandable writing style was strongly linked to improved recall scores among the participants. This suggests that writing clarity can have a strong, measurable impact on how effectively researchers are able to communicate their ideas. This is supported by previous research which found similar trends when it came to writing quality and recall (Ryba et al. 2021). In particular,

narrative structure – such as the kind facilitated by personal language and a focus on connective language – is strongly associated with improved recall (Negrete 2021).

As might be expected, our subjects typically found the hard abstract easier to recall if they had previously read the easy abstract. This learning effect was only present for the hard abstracts, suggesting that the easy abstract was understandable even without the benefits of prior knowledge. In contrast, people reading hard abstracts benefitted from being previously exposed to an easier version of the text and faced greater challenges understanding the abstract otherwise. In addition to easing genuine reader understanding, being able to understand the abstract will provide the reader with the confidence that they will be able to understand the rest of the paper (Pain 2016).

While this insight is interesting, in future studies (especially ones that do not include the EEG component and thus are easier to recruit for) it may be beneficial to use an incomplete experimental design. In this scenario, there would be two abstract topics and four abstracts in total – one easy and one hard for each topic. Each participant could then be presented with an easy abstract for one of the topics and a hard abstract for the other. This would aid with gaining a stronger understanding of the impact of writing style as opposed to learning effects.

In addition to their improved recall, our subjects consistently self-reported a personal, subjective preference for the abstract written in easy-to-understand language. Our subjects clearly indicated that the abstract written with an eye for clarity was easier to read, they had more confidence in their understanding, they enjoyed reading the abstract more, and it required less mental effort on their part.

These results may give further insight into the exact styles of writing which help to improve audience engagement and recall and thus help overcome the divide between scientists and their readers. The results of our analysis indicate that abstracts intentionally written to include certain writing features associated with clarity can boost reader understanding and confidence in their understanding (Ryba et al. 2021). Namely, we find that readers can more easily engage with texts that: limit the use of acronyms (Narod, Ahmed & Akbari 2016), use short paragraphs and sentences (Katzoff 1964), use personal language and an active voice (Li et al. 2018), limit jargon to strictly necessary implementation only (Bullock et al. 2019), and use clear linking language to connect different ideas to one another (Pinker 2014).

In particular, the increase in recall as a result of clear writing adds further support to the theory of cognitive load. This theory states that working memory is limited and a reader can only transfer a limited amount of information into their long-term memory at one time. Importantly, this transfer requires that the information in question is not only passively viewed, but understood (at least in part). Therefore, a message in a scientific journal can be more quickly and easily conveyed if the writer attempts to write in a way which is more easily understandable (Sweller, van Merrienboer & Paas 1988). This theory is supported by the clear increase in recall seen when participants read the abstract written with a specific focus on clarity.

This knowledge of the features of writing that most benefit readers can be used to help develop a better understanding of how to gauge writing quality. Currently, there is some debate as to the best way to achieve this aim. Readability matrices are popular and have the benefit of being simple to automate. However, it is unclear as to whether they accurately reflect the style of writing that most benefits readers, as the elements of a text they examine tend to be limited (DuBay 2004). So it may be that a more complex "rubric" of writing features is required to judge writing quality. We hope that the results from this study can be used to help develop such a rubric, which in turn can be used to guide scientific writers as to the most important elements to focus on for the sake of their readership. It is often observed that scientific authors often lack the dedicated training needed to write effectively (Ritchie et al. 2022), so having a clear set of elements which can help improve scientific writing may benefit these authors.

To this end, it could provide useful insight if this experiment was rerun with a wider variety of abstracts. Each of these abstracts could focus on one specific writing characteristic. For example, one abstract could include several acronyms but have a strong narrative structure, while the other could have a weak narrative structure but no acronyms. This contrasts with the binary division of easy versus hard writing used in the experiment we conducted. This change could help us develop a more refined understanding of which specific writing characteristics best help to improve recall, generate positive opinions on the text, and reduce mental burden. In turn, this would give scientific writers clear and effective "goalposts" when it comes to constructing their papers, regardless of if they have any formal training or not.

Conclusion

While many researchers struggle with writing due to a lack of confidence and training, it is still important that they attempt to convey their ideas. After all, the process of science necessitates that researchers are able to share their ideas with others (Abraham 2020). By focusing on key elements

of writing such as avoiding jargon and clearly connecting ideas, scientists can ensure that their work is fully understood by a wider range of people. This in turn benefits the researchers themselves, as they can convey their ideas more accurately and may even gain more citations and overall engagement as a result (Hohmann & Connell 2025; Sawyer, Laran & Xu, 2008).

It is clear from these results that improved writing quality can indeed have a major positive effect on the ways readers engage with scientific writing, both on an emotional and intellectual level. When reading an abstract written with an eye for clarity, readers are far more able to positively engage with the text and recall its contents. This suggests that there are strong benefits that a scientist can reap by focusing on strong scientific writing.

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Principal Author

Name of Principal Author (Candidate)	Mollie Hawkes Hohmann		
Contribution to the Paper	Concept and design; Analysis and interpretation; Multiple drafts; Critical Revision		
Overall percentage (%)	90%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	22/08/2025

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sean D Connell		
Contribution to the Paper	10% - Concept and design; Interpretation, drafting and proofreading; Multiple critical revisions		
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Comparing the writing styles of highly and rarely cited papers in conservation biology

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ABSTRACT

For the everyday scientist, being published – and henceforth cited – is a major enterprise. An understanding of the components associated with highly-cited conservation papers is therefore of interest to environmental scientists. In this study, we examined common features of scientific writing to examine their relationship with highly-cited conservation papers. We did this by searching the Web of Science database for biodiversity conservation papers and examined the differences between the 500 most-cited papers and the 500 least-cited papers. Highly-cited papers tended to include broad titles, use motivational language, use conceptual images, and included clear explanations of the broader context and relevance of their research. The popularity and reach of the journal also played an important role, as did the proportion of female authors in an authorship team. When writing a paper, environmental scientists can try to ensure their research is both clear and inspiring to a wide range of people using these features so their message is received by a broader readership.

1. Introduction

While many picture scientists hunched over test tubes or crawling through the wilds in search of rare samples, in truth, much of our time is spent writing. For hundreds of years, science has been a collaborative work spread via the written word. In many areas of writing there is a trend towards greater readability. Both US presidential speeches and news articles show trends towards increasingly simplistic language over time (Plavén-Sigray et al., 2017). But this is not the case for scientific writing. Current medical articles are as hard to read as legal contracts (Yeung et al., 2018). To make matters worse, several researchers have found evidence that the readability of scientific papers is decreasing over time (Graf-Vlachy, 2021; Jeong et al., 2021; Plavén-Sigray et al., 2017).

The writing style of scientific articles significantly affects audience engagement and citation rates. For example, using jargon in titles and abstracts negatively impacts citations as it assumes reader familiarity with the topic (Martínez and Mammola, 2021). This can lead to fewer citations and potential misinterpretations of the paper's content (Todd et al., 2010). Unclear writing limits public and non-expert comprehension of scientific work. High cognitive load – the mental effort required to understand a text – impairs reader comprehension and recall, contributing to a disconnect between scientific discoveries and public understanding (Ayres, 2006; Sweller, 1994; Wang et al., 2020). But cognitive load can be reduced with inspiring writing techniques (Britton et al., 1982; Jeong et al., 2021). Effective communication is crucial for advancing societal knowledge and ensuring that scientific findings are accessible to all, not just experts.

Traditional scientific writing seeks to address the issue of dense writing through clarity. This focus on clarity is intended to enable writers to overcome the issues of high cognitive load, allowing readers to accurately comprehend and build upon the work presented. Yet, effective communication requires both clear *and* inspirational writing to connect with readers. Both types of writing require considerable effort (Montgomery, 2003). Clear writing aims to present information in a logical order and use precise language, whereas inspiring writing uses creative and motivational language. Inspiring language can capture a reader's attention by appealing to their curiosity, making the content more relevant, engaging, and memorable (Doubleday and Connell, 2017; Freeling et al., 2021).

Clear and engaging writing is particularly important in conservation biology due to the need for multidisciplinary readers to easily understand the research. Conservation biology intersects with various fields such as environmental science, policy, economics, and sociology, making it essential for researchers from different disciplines to comprehend the work. Accessible writing enhances collaboration, allowing experts

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from diverse backgrounds to integrate their knowledge and approaches to address complex conservation issues more effectively. Unlike fields such as theoretical physics, conservation biology often aims to maximise the impact of its work through outreach and engagement beyond citations. Scientists use social media and other platforms to share discoveries and attract the attention of NGOs and policymakers, which can lead to funding and support (Mandl et al., 2023). Therefore, emphasising accessible language in conservation biology papers is crucial for fostering interdisciplinary collaboration and ensuring the research has a broad and impactful reach.

When a reader browses a scientific paper, they tend to focus on a few key areas first in order to determine if the paper is useful for their purpose, as depicted in Fig. 1 (Rothmund and Stinner, 1998). Readers will generally first focus on the title of the article (Armson, 1993; Pain, 2016; Rothmund and Stinner, 1998), followed by the abstract (Pain, 2016; Rutkowski, 2020). They will then be drawn to any supporting graphics (Armson, 1993; Pain, 2016; Sun, 2020), followed by the first body paragraph (Pain, 2016; Rutkowski, 2020; Sun, 2020), and then finish by reading the conclusions of the paper (Armson, 1993; Pain, 2016; Rothmund and Stinner, 1998). Once they have read these sections, the reader can then judge the merits of the papers and decide if it is worth reading any further. Therefore, it is valuable for scientists who are writing a paper to put extra care and attention into these areas, in order to draw in readers who are assessing their work to determine its merits.

We focused our investigation on these key areas of the paper. We hypothesise that when the presentation of concepts is broad enough to provide a clear and engaging context, uses clearly motivated language, and has inspiring graphical support with motivating figure legends – these papers will attract readers who will go on to read the paper in-depth and therefore find sufficient value to warrant citing the paper. We predicted that the impact of these features is stronger than the influence of author gender, journal impact factor, or the use of press releases on the part of the journal. We tested these hypotheses by correlating these linguistic features with the number of citations a paper receives.

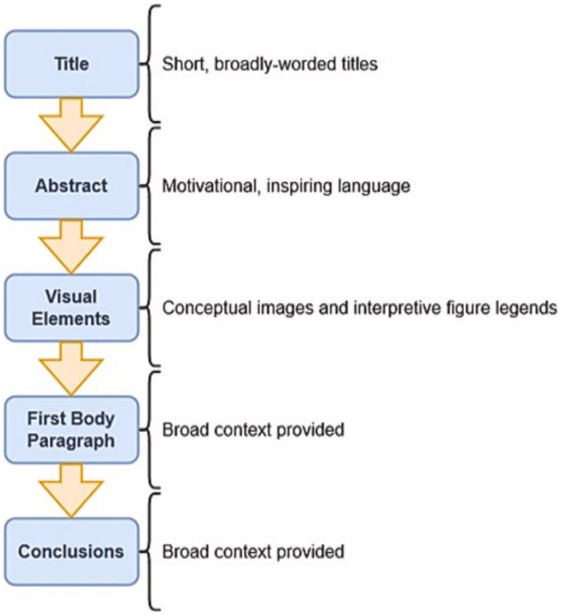

Fig. 1. Writers can attempt to engage the readers' interest by focusing on areas where readers tend to scan when skimming a paper (Armson, 1993; Pain, 2016; Rothmund and Stinner, 1998; Rutkowski, 2020; Sun, 2020).

2. Methods

We focused on the areas that readers initially read when evaluating relevance and importance of a scientific paper. These focus areas were the title (Armson, 1993; Pain, 2016; Rothmund and Stinner, 1998), abstract (Pain, 2016; Rutkowski, 2020; Sun, 2020), supporting graphics (Armson, 1993; Pain, 2016; Sun, 2020), the first body paragraph (Pain, 2016; Rutkowski, 2020), and the conclusions of the paper (Armson, 1993; Pain, 2016; Rothmund and Stinner, 1998). Importantly, while the abstracts of articles are generally less readable than the full text, there is a strong positive relationship between the readability of abstracts and the full text (Plavén-Sigray et al., 2017). This indicates the abstract is valuable to judging a paper as a whole.

For this study, we examined a number of papers from the Web of Science database. We initially refined the data by searching for "environ*" in the topic field (in order to pick up terms such as environment, environmentally, environmental, etc.). We then further refined this search by, "Research Areas: Biodiversity Conservation", "Publication Years: 2015 or 2014 or 2013 or 2012 or 2011", and "Document Types: Articles". The 'Article' document type filters out erratum and news summaries. We chose to examine papers published from 2011 to 2015 in order to ensure they had sufficient time to be cited by a wide range of authors, but otherwise we did not control for the year of publication (see Supplementary File A).

We sorted the papers by "Citations: highest first" and "Citations: lowest first". We examined the first five hundred papers for each of these two categories – ignoring any methods and review papers found in this search, papers that were not written in English, and any papers that could not be accessed via our usual databases. In doing so, we gathered a sample of 1000 papers, 500 of which were highly-cited and 500 of which were rarely-cited. Supplementary File B explains our rationale behind this sample size.

We then examined the role inspiring writing has on a paper's impact by observing the differences between highly-cited and rarely-cited papers. One researcher read the key areas of each paper we had gathered and scored whether they did or did not use various writing features. This researcher was not blinded as to whether the papers were highly or rarely-cited, however, we used a semi-random method of ordering the papers for the purposes of scoring. We tested whether there was observer bias by selecting a sub-sample of the papers and providing them to two independent researchers for review. Each of these reviewers received 50 such papers ($n = 100$). We found no evidence of confirmation bias (see Supplementary File C).

The papers that used a writing feature were given a score of 1 for that category and those that did not were given a score of 0. We used a *Z*-test to test whether there were differences between highly and rarely cited papers for each of the linguistic features listed below.

2.1. Breadth

Writing that gives a reader broad context for the research. Breadth is important because it enables readers to quickly and easily draw connections between the paper and their own research, which may not necessarily be within their exact sub-discipline (ElShafie, 2018).

- Broad Title – Whether the paper's title is broadly inclusive, rather than exclusively focusing on specifics (e.g. if the title mentioned a specific species, place, or time). The balance between brevity and information needs care (Kane, 2000).
- Title Length – Articles with shorter titles attract more attention compared to articles with longer titles (Jamali and Nikzad, 2011). Short titles help to enforce breadth. Title length was calculated using the total number of words per title.
- Broad First Line of Abstract – Whether the first line of the paper's abstract made mention of the broader literature surrounding the

topic at hand or spoke of the broader importance of the study, or if it solely concerned itself with the methods or results of the study itself.
- Broad Last Line of Abstract – As above, but with the last line of the abstract.
- Broad First Paragraph – As above, but with the first paragraph of the paper.
- Broad Last Paragraph – As above, but with the last paragraph of the paper.

2.2. Motivational language

We examined the abstracts of the paper for examples of motivational language. Examples of language which was considered motivational includes "urgent need", "radically alter", and "extremely fragile". Motivational language can attract reader attention (Hohmann et al., 2023), but it can also act against objectivity (Mammola, 2020). Motivational language only needed to be used once to count. Supplementary File D consists of a list of words considered "motivational" by this study.

2.3. Visual elements

Visual elements help to attract the attention of readers and can communicate complex ideas in a way which is more readily understandable than text alone (Kim et al., 2022; Pérez-Llantada and Luzón, 2019). Detailed figure legends act as a supplement to visual elements by guiding a reader's understanding of visual elements and can draw their attention to key components of an image (Kroodsma, 2000; Liu et al., 2023).

- Use of Conceptual Images – Whether the paper had at least one image that was used to represent the theoretical ideas under examination. This is in opposition to images such as graphs, which represent "hard" data.
- Use of Interpretive Figure Legends – Whether the paper used interpretive figure legends on any of its figures. Interpretive figure legends were defined as legends that contain some amount of interpretation to aid reader understanding, instead of only having descriptions of the data.

To gain a more complete understanding of the impact of writing features on the number of citations a paper received, we ran a multiple factor analysis test via the RStudio 'FactoMineR' package (Lê et al., 2008). The multiple factor analysis allowed us to explore other factors that may impact on citation frequency – namely the impact factor of the journal and the gender of the author/s. We tested the effect of gender in two ways. First, we recorded the gender of the primary author of each paper. Second, we calculated the proportion of female authors within each authorship team. We tested the effect of journal impact factor by calculating the average 5-year impact factor of our sample, which came to 5.04. We then classified all journals that fell below this threshold as "low-impact", and all journals above that as "high-impact". To test the impact of press releases we simply examined the total for each sample.

It can be anticipated that papers with broad titles will often reflect the broad nature of their topic. To account for this, we ran tests to determine if the citation rate of papers with "broad titles" was a result of "broad topics". To do this, we randomly selected 100 papers each from the high and rarely-cited samples. We assessed whether these papers were based on broad topics. We defined a topic as being broad if the study took place over multiple countries, or if the paper applied its research to address global issues. We scored each paper that had a disparity between the broadness of the title and its topic a value of 1, and papers that did not have this difference as 0. We used these results to run a Chi-square test to determine the differences between the highly and rarely-cited papers.

3. Results

We found that papers which used broad language in their title were more likely to be cited. Highly-cited papers were 37.2 % more likely to have a title that did not reference a specific time, species, or location compared to rarely-cited papers (Fig. 2, see Supplementary File E for analysis of statistical significance).

On average, highly-cited papers had slightly shorter titles compared to rarely-cited papers (Fig. 2).

"Broad" language was defined as terms that either provided background information, or gave examples of the broader relevance of the study to the field in question. In contrast, specific language was language that was concerned only with the study itself and didn't attempt to tie the study into the literature as a whole. We found that highly-cited papers were significantly more likely to use broad language when compared to rarely-cited papers. For example, highly-cited papers were 25.2 % more likely to use broad language in their first paragraph (Fig. 2).

We examined each of the abstracts to see where motivational language was used (e.g. terms such as "essential", "imperative", and "backbone"). We found that highly-cited papers were 22.2 % more likely to use this kind of language compared to rarely-cited papers (Fig. 2).

The use of conceptual images – which we defined as figures used to communicate concepts rather than raw data – was limited in both low-citation and high-citation papers. However, highly-cited papers were still 12.6 % more likely to use conceptual images compared to rarely-cited papers (Fig. 2).

Similarly, highly-cited papers were more likely to use interpretive figure legends, which we defined as figure legends that include some form of analysis as opposed to merely describing the findings. While the use of interpretive figure legends was limited, highly-cited papers were 4 % more likely to use them compared to rarely-cited papers (Fig. 2).

Our multiple factor analysis provided further evidence that the use of broad language combined with the use of motivational language is associated with an increase in the number of citations a paper receives (see Fig. 3).

Researchers may reflect on the influence of gender and media engagement on citations. We detected a subtle effect of the gender of the authors on citations per paper. The gender of the primary author was not detected to have a significant effect on citation rate (categorical test: Chi-Square: 0.017, $p = 0.896$), yet we detected an effect of the proportion of female co-authors (continuous test: ANOVA, $F_{1,937} = 10.18$, $p = 0.001$). We detected a slightly smaller proportion of female researchers authoring high-citation papers (29 % female, 71 % male) compared to low-citation papers (35 % female, 65 % male). For journals that provided in-house press releases, it is not clear to what extent they might boost citations. Of the papers examined, there were two highly-cited journals that employed in-house press releases compared to eighteen papers journals from rarely-cited journals.

As anticipated, journal impact factor had a significant impact on citation frequency (ANOVA, $F_{1,993} = 1205$, $p < 0.001$). Upon further testing the relationship between journal impact factor and writing style, we discovered that this relationship showed a very similar pattern to the relationship between writing style and citations (Fig. 4). This indicates that these factors are closely correlated to each other.

Unsurprisingly, papers with broader titles were more likely to be cited. Highly-cited papers were 37.2 % more likely to have broad titles and usually did not reference specific times, species, or locations compared to rarely-cited papers (Fig. 2). However, we wanted to make sure that this was not simply because papers with broad titles were about broader topics, which tend to be relevant to a larger pool of researchers. From a random sample of 100 high-citation and 100 low-citation papers, we found that papers covering broad topics were indeed cited more frequently. Specifically, 14 % of highly-cited papers focused on broad topics, while only 4 % of rarely-cited papers addressed broad topics (Table 1).

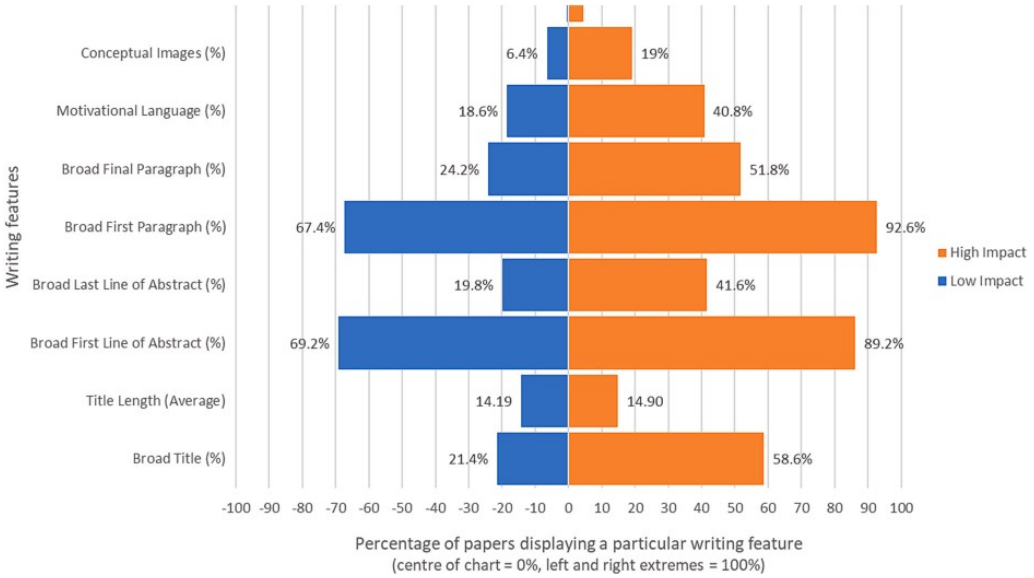

Fig. 2. This figure shows how different linguistic styles affect citations, where rarely-cited papers are depicted in blue (left) and highly-cited papers in orange (right) ($n = 500$ for each). Title length is displayed as an average rather than a percentage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

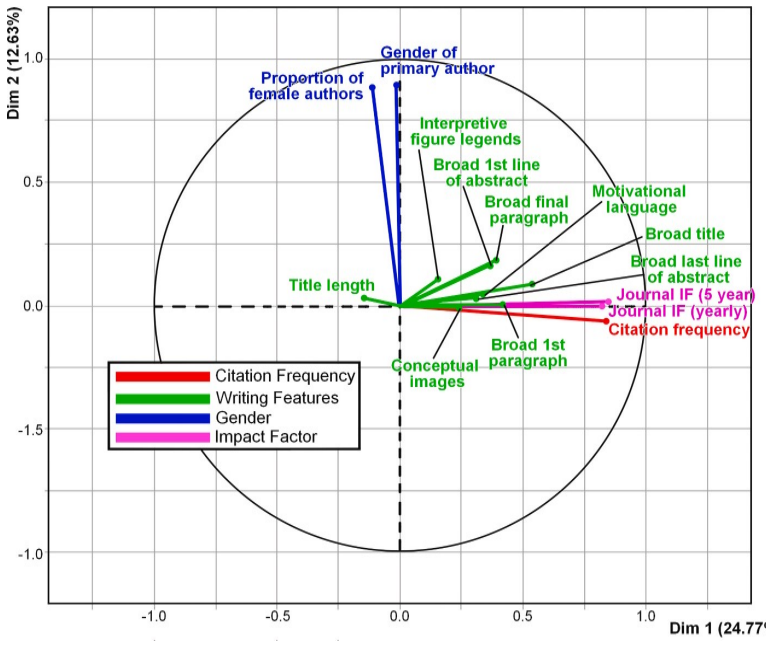

Fig. 3. A multiple factor analysis graph showing the factors that influence the number of citations scientific papers receive. Citations are indicated in red, writing features in green, journal impact factor in pink, and the gender of the author/s in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

We also examined how often broad titles were used to describe narrow topics and vice versa (i.e., narrow titles used for broad topics), and how this influenced citation rates. Our findings show that highly-cited papers were much more likely to use broad titles for narrow topics. Among highly-cited papers, 43 % used a broad title for a narrow topic, compared to 20 % of low-cited papers (Chi, p-value <0.001). Interestingly, when the titles exceeded the inference of their actual topic, they tended to be more highly-cited (68.35 %) then those which

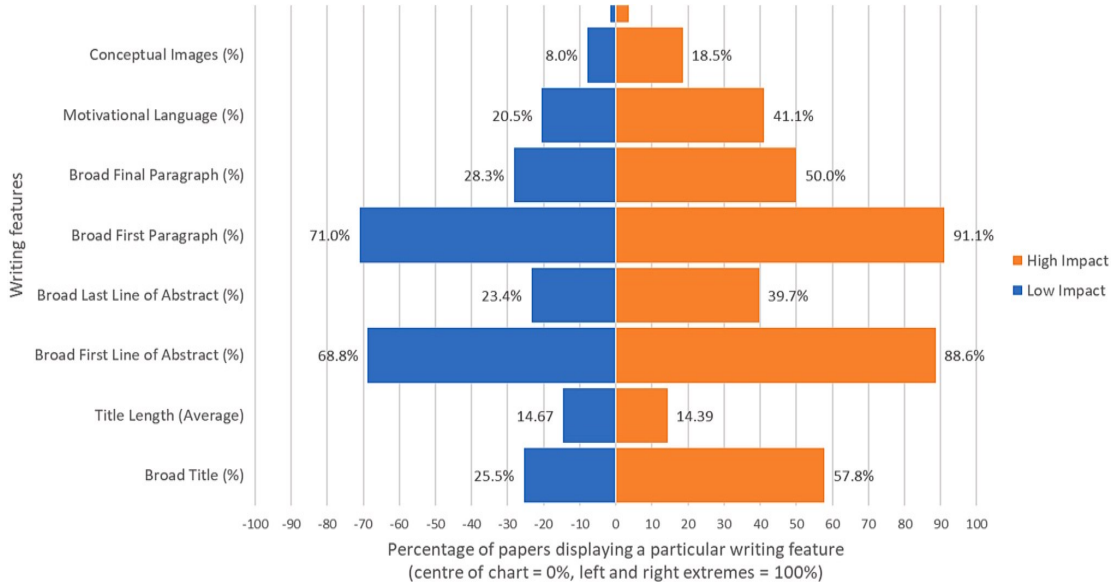

Fig. 4. This figure shows how the writing style of papers change with journal impact factor, where low impact journals are depicted in blue (left; $n = 552$) and high impact journals in orange (right; $n = 448$). Title length is displayed as an average rather than a percentage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
The proportion of highly and rarely-cited papers that presented their research with broad titles (first column) and where papers were based on broad topics (second column).

	Broad Title (%)	Broad Topic (%)
Highly Cited Papers (n = 100)	55 %	14 %
Rarely Cited Papers (n = 100)	23 %	4 %

had a narrow title to match their topic (36.1 %). However, if the topic is broad, the papers tend to be highly-cited independently of the breadth of the title (80.0 % for broad title and broad topic, compared to 66.77 % narrow title and broad topic). For clarity, these latter comparisons represent the percentage of highly-cited papers within each of these four categories, i.e. they are not comparisons among the four categories (as shown in Table 2).

Table 2
The percentage of occurrence of papers among the four possible combinations of broadness of title (narrow and broad) to the broadness of their topics (narrow and broad). Totals across rows add to 100 %.

	Narrow Title and Narrow Topic (%)	Broad Title and Broad Topic (%)	Narrow Title and Broad Topic (%)	Broad Title and Narrow Topic (%)
Highly Cited Papers (n = 100)	43 %	12 %	2 %	43 %
Rarely Cited Papers (n = 100)	76 %	3 %	1 %	20 %

4. Discussion

Scientists have been advocating for better writing for decades (Alley, 1996; Meredith, 1966; Peterson, 1961), but despite this advocacy, several researchers have found evidence that the readability of scientific texts is decreasing over time (Barnett and Doubleday, 2020; Graf-Vlachy, 2021; Vergoulis et al., 2019). These changes result in miscommunication between scientific colleagues (Freeling et al., 2019; Hillier et al., 2016; Seymour et al., 2015). Scientists can seek to address this issue by focusing on writing clearly in order to support reader understanding (Sweller et al., 1988; Sweller, 1994).

Clear writing has been linked to increased citations – a major concern for all practising scientists (Jeong et al., 2021). Some papers have found clear positive links between highly "readable" academic papers and the number of citations they received (Martínez and Mammola, 2021; Jeong et al., 2021; Sawyer et al., 2008). But other researchers dispute these findings and report that lower levels of readability are associated with a greater impact (Dolnicar and Chapple, 2015; Lei and Yan, 2016; Stremersch et al., 2007). This discrepancy is likely to be due the interdisciplinary nature of the research and the varying methodologies used (Begeny and Greene, 2013). However, both "camps" agree that clear writing is important (Britton et al., 1982; Dolnicar and Chapple, 2015; Lei and Yan, 2016).

Despite clear writing being championed as a key aim of scientific writing, there have been increasing calls for inspiring writing which helps readers engage with the work and understand why it is important (Doubleday and Connell, 2017; Montgomery, 2003). One way of connecting to and inspiring readers on this deeper level is to use visual cues (Kroodsma, 2000; Pérez-Llantada and Luzón, 2019). Conceptual images and interpretive figure legends can be used to aid readers in interpreting a paper. We found that papers which used conceptual images and interpretive figure legends were more likely to be cited. This represents a relatively easy way for researchers to promote their papers. As these features – especially the latter – are not commonly used, papers that *do* use them can quickly "stand out".

Researchers can use various writing techniques alongside graphical

cues to inspire readers. Our analysis found that highly-cited papers were more than twice as likely to use motivational language compared to rarely-cited ones. Yet, this approach can lead to sensationalism, compromising accuracy and objectivity to attract attention. Institutions often incentivize researchers to publish high-impact papers, creating an incentive to over-hype findings (Bornmann, 2010). This pressure undermines objectivity and truth in scientific discourse. Using motivational language to engage readers is poor scholarship and Doubleday and Connell (2017) encourage researchers to employ other linguistic strategies that maintain integrity.

Writers can strive to make their work clearer by providing background context that explains the state of the field and the place of the research within it. This allows readers who do not have a deep background in the field to understand the work and how they might apply it in their own life (Bahadoran et al., 2018; Dodson, 2015). The use of broad language in a paper can also help to inspire readers by enabling them to quickly and easily draw connections between the paper and wider research, understand the importance of the study, and apply the results of the paper to their own field of study (Bahadoran et al., 2018; Lindsay, 2011; Mensh and Kording, 2017). We found that, compared to rarely-cited papers, highly-cited papers are significantly more likely to use broad language in both their abstracts and the body of their papers.

Broad language, used in the title of a paper, allows readers to more easily imagine how the paper might relate to their work. The relationship we found between broad titles and broad topics suggested that high-citation papers are indeed more likely to focus on a broad topic. However, we also found that high-citation papers are significantly more likely to use a broad title to describe a narrow topic. Papers with broader titles therefore tend to get cited more frequently, regardless of the breath of the topic. Papers based on specific subjects or foci should always exist, but by placing the topic in a more broadly understandable context, authors can allow a broader range of readers to understand how the study may apply to their own work.

Researchers may consider the influence of gender and media on citation patterns. Our analysis revealed a subtle effect of gender of author on citation rates. Previous research has reflected on challenges for female authors (Chatterjee and Werner, 2021) including fields with long lags between doctoral education and faculty appointments, such as ecology (Larivière et al., 2013). In our own study, we found that female authors accounted for a third of authors on average. Importantly, females as lead authors were cited equally to males, yet a subtle negative effect was detected for teams comprising a greater proportion of female researchers; they were cited slightly less among highly-cited papers. Our preliminary analysis of the influence of press-releases is not highly informative, albeit our comparison pointed to a limited boost to citations.

We found very strong similarities in the relationships between citation frequency versus writing style and impact factor versus writing style. Whilst citations do indeed reflect the impact factor of a journal and its associated writing style, the relationship between writing style and citations we detected is meaningful. Writing style varies in a consistent manner with journal impact factor. The origin of higher-impact styles of writing is unclear, but there are a few we would like to suggest. Firstly, it could be a result of mimicry on the part of the writers. Writers may – consciously or unconsciously – attempt to mimic the writing styles of previous successful papers (Hodges and Narum, 2015). This leads to journals developing a writing style where researchers copy one another's style. Another potential explanation is that high-impact journals are more willing to be selective with the papers they publish, selecting papers with a clear and inspiring writing style.

A limitation to this study is that citation frequency will inevitably vary due to the popularity of the research topic and the perceived significance of the cited work. However, this does not change the fact that we identified clear differences in the writing styles of high- and low-citation papers. While we cannot confirm a causal relationship, it is likely influenced by multiple factors. Future studies could explore key drivers of citations for high-impact studies and examine how citation patterns, topic of research, gender of author, promotion by social media, and style of writing interact.

Clear writing and inspired writing serve different purposes, but both contribute to effective communication. There is a readily-apparent cultural push for clear writing among scientists, but inspiring language should not be forgotten. The exact relationship between the influence of a paper and its readability remains under-researched, but more readable writing is vitally important to progressing conservation biology. By focusing on improving our writing, researchers can better place our research in the wider context of the field, thus allowing people to more effectively build on our work.

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CRediT authorship contribution statement

Mollie Hawkes Hohmann: Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Sean D. Connell:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

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Data availability

Data will be made available on request.

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Principal Author

Name of Principal Author (Candidate)	Mollie Hawkes Hohmann		
Contribution to the Paper	Concept and design; Analysis and interpretation; Multiple drafts; Critical Revision		
Overall percentage (%)	90%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	22/08/2025

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

iv. the candidate's stated contribution to the publication is accurate (as detailed above);

v. permission is granted for the candidate in include the publication in the thesis; and

vi. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sean D Connell		
Contribution to the Paper	10% - Concept and design; Interpretation, drafting and proofreading; Multiple critical revisions		
Signature		Signature	22/08/2025

Chapter 5: Numbers or words: What matters more for succeeding in university biology?

Abstract

Science is typically regarded to be a quantitative discipline that prioritises "hard" skills such as mathematics and statistics. However, there is a growing consideration of the vital role that strong writing and communication skills play in scientific success. Despite this, many university science programs continue to emphasise quantitative skill development while giving less attention to literacy. In this study, we examined the relative contribution of literacy and numeracy skills on the performance of undergraduate biology, measured by student aggregate grades. Our findings show that while numeracy is indeed an important predictor of success, literacy skills also play a significant role. Notably, students who reported reading fiction regularly tended to have stronger literacy skills. However, strong mathematical ability did not predict strong literacy skills. These findings suggest that science students would benefit from curricula that place a greater emphasis on reading and writing; skills that are essential for becoming effective and well-rounded scientists.

Introduction

Traditionally, universities have considered quantitative skills to be the clearest indication of scientific understanding in their students, with qualitative skills being a secondary concern (Cirino et al. 2017; Sears & Sorenson 2001). The institutional distinctions that still exist between science, technology, engineering, and maths (STEM) departments and humanities departments demonstrates this attitude. It is true that quantitative skills are vitally important for students if they are to become successful scientists. However, it is also important that science students develop strong writing skills. After all, those students who continue in the field of research-based science will occupy a large chunk of their career with writing papers. Universities have the chance to help their students develop the skills needed to write in a way which can be easily understood by a wide range of people.

There are many benefits that students may see in their careers if they have been taught to write in an understandable way. Firstly, clear writing ensures that their work can be correctly cited by scientific colleagues who work in the same field. In contrast, if they cannot write clearly, they may struggle to obtain citations and may even find that their work is cited incorrectly (Sawyer, Laran & Xu, 2008; Martínez & Mammola 2021; Todd et al. 2010). Clear writing can also broaden a researcher's reach outside of their chosen speciality allowing non-specialists to understand and thus build upon their work (Martínez & Mammola 2021; The National Academies 2005).

In addition to aiding communication between scientific colleagues, clear writing can help educate the general public about the processes of science. Today, the world is increasingly interconnected by the internet, making it easier than ever for members of the public to engage in scientific research. But if they cannot understand reliable scientific voices, they will turn to unreliable sources instead (Seymour et al. 2015). Therefore, it is useful if scientists can write in a clear voice, unobscured by jargon and other dense writing practices (Seymour et al. 2015; Vergoulis et al. 2019).

Science courses can prepare students for their career by providing them with strong writing skills which enable them to reach a wide range of people. However, we would question how science students are taught to write at a university level. Universities have an ethical interest in knowing if the literacy and numeracy skills their students obtain throughout their studies prepare them for the workforce. Currently, it seems that students are not being taught how to write, with 72% of universities lacking easily accessible science communication training (Ritchie et al. 2022). Many graduate and post-doctoral students agree that they have not been adequately trained to write during their studies and lack confidence in their writing abilities (Glew, Challa & Gopalan 2014). The fact that these students are not taught to write also raises the questions of how literacy and numeracy skills intersect, the external factors that influence the development of these skills, and the ways these skills impact student success.

To determine if university students are being taught the skills necessary to become successful scientists, we tested a sample of third-year biology students. We assessed their literacy and numeracy skills and compared them to the aggregate score of their undergraduate grades (their Grade Point Average/GPA) as a measure of student success. We did this to see which skills were more closely linked to student success. In order to investigate other factors that could influence numeracy and literacy skills, we surveyed the students to determine how they engaged with maths and writing throughout their degree and personal lives. We also assessed the metrics of those teaching scientific writing as there is a sense that high level researchers with prestigious research metrics are not being assigned to teach science writing and communication. We test that hypothesis here and discuss in combination with the benefits of placing a greater emphasis on reading and writing to train more successful scientists.

Methods

In March of 2022, 2023, and 2024 we recruited biology students from a third-year statistics course aimed at students studying biological science degrees at the University of Adelaide (n = 56). Over the course of three weekly laboratories we asked said students to complete a literacy test, a

numeracy test, and a brief survey at a rate of one test/survey per week. Each of these papers were marked with a code which was unique to each respondent but unidentifiable to a specific person, allowing us to compare the three responses for each respondent.

The literacy test was composed of blocks of text, followed by multiple-choice questions that were mostly based around potential changes to the grammar of the text. The numeracy test was composed of several multiple-choice maths questions. The final four questions of the numeracy test were not multiple choice, instead requiring the respondent to calculate the answer. The survey included questions about the respondents' GPA and personal reading habits.

We summed the results for the literacy and numeracy test and converted them into a percentage score to allow for comparison, as the literacy and numeracy tests had a different number of questions.

In cases where the student attempted less than half of the questions in the literacy or numeracy tests, we removed said student from the sample for that analysis. In cases where the student provided a range for the average number of books/articles they read per year, we entered this as the median number within the range (e.g. if they responded that the read 5-8 fiction books per year, we said they read 6.5 fiction books per year). There were also a few students who filled out the survey questions regarding their reading habits in error, who we removed from the analysis of this area.

We used R-Studio and R-Commander to run multivariate linear regression analyses and Spearman tests on the data collected. Prior to this we used Excel's RANK function to calculate ranks for the key areas of the data. We used ranked data given the potential for non-linear relationships and robustness to outliers not only for univariate tests of association (i.e. Spearman's test), but also multi-variate that seeks to test the relative order of importance of multiple variables (Tyagi et al. 2023). To visualise these multivariate relationships, we plotted a principal component analysis (PCA) graph alongside graphs of correlation to identify the relationship between literacy and numeracy scores, and their relationship to GPA (Lê, Josse & Husson 2008; Sou & Nagashima 2019).

To further our understanding of the state of science communication education, we examined which researchers are teaching STEM at a university level. We sampled several universities from within Australia, the United Kingdom, and the United States. From these universities we selected science

communication subjects, basic ecology or biology subjects, and statistics subjects aimed at biological science students. We then looked up the course coordinators for these classes on Scopus to find their h-index, number of publications, and number of citations. We averaged these results for each of the three subject categories. To visualise the data, we plotted a graph comparing the publication frequency of these coordinators against their H-index. To further test our results, we compared these three subject categories within institutions (see Appendix I).

Results

Multivariate linear regression

From our multivariate regression analysis (shown in Table 1) we found that numeracy clearly contributes to GPA. The individual regressions were also statistically significant at $p = 0.002$ ($R^2 = 0.149$, $F_{1, 58} = 10.12$). Literacy also contributes, though to a somewhat lesser degree ($R^2 = 0.090$, $F_{1, 54} = 5.365$, $p = 0.030$; see Figure 1). However, these two skills do not correlate to one another (see Figure 2).

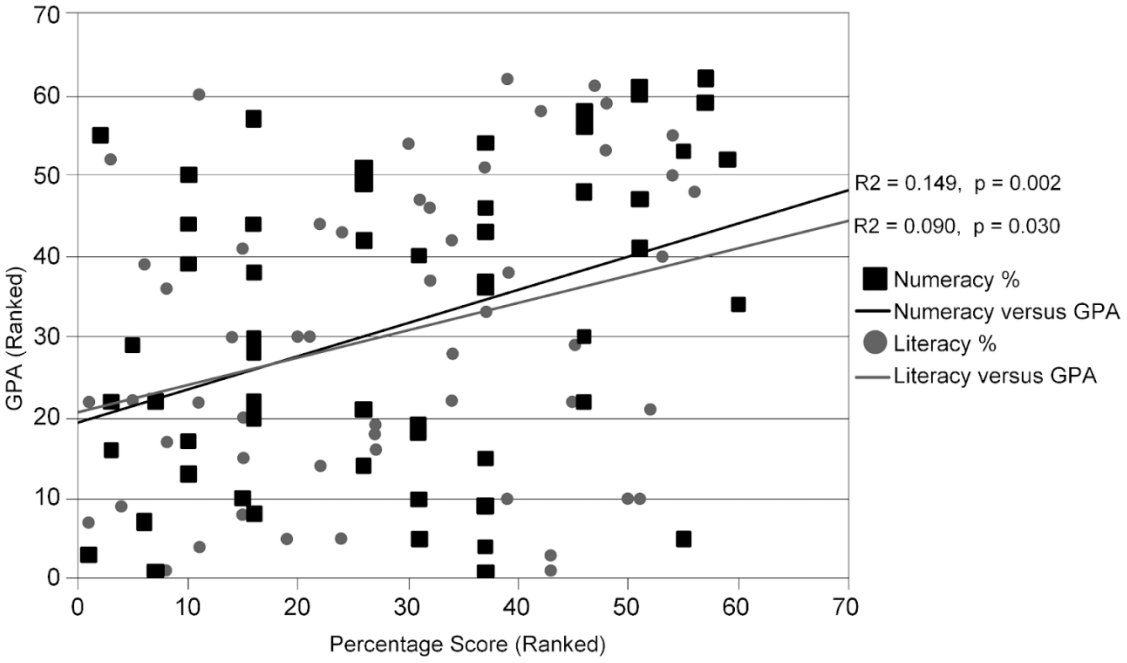

Figure 1 *A scatterplot showing the relationship between numeracy skills and literacy skills compared to student grade-point average (GPA). The ranked value for GPA is displayed on the y-axis, on a scale from 0-70. Numeracy and literacy skills are displayed as a ranked value for percentage on the x-axis. Numeracy scores are represented by black squares, while literacy scores are represented by grey circles. Figure generated in LibreOffice Calc and edited in Fire Alpaca.*

Table 1 *Results of the multivariate linear regression tests. The included measures are: p-value, R^2. F-statistic (with degrees of freedom), standard error, estimates, and 95% confidence intervals.*

Literacy % and Numeracy % versus GPA	**p-value**	**Estimate**	**SE**	**CI (95%)**
Literacy % versus GPA	0.013	0.343	0.134	0.075–0.612
Numeracy % versus GPA	0.001	0.441	0.129	0.183–0.699
Intercept	0.154	8.195	5.662	-3.167–19.557
$R^2 = 0.258, F_{2, 52} = 9.049$				
Reading Fiction, Nonfiction, and Articles versus Literacy %				
Fiction Books Read Per Year versus Literacy %	0.011	0.385	0.146	0.092–0.679
Nonfiction Books Read Per Year versus Literacy %	0.594	0.083	0.142	-0.203–0.368
Journal Articles Read per Year versus Literacy %	0.749	0.044	0.136	-0.230–0.318
Intercept	0.020	15.445	6.420	2.530–28.360
$R^2 = 0.139, F_{3, 47} = 2.539$				
Fiction Books Read per Year versus Literacy %	0.008	0.377	0.136	0.104–0.649
Intercept	0.001	18.811	4.167	10.446–27.175
$R^2 = 0.131, F_{1, 51} = 7.691$				
Reading Fiction, Nonfiction, and Articles versus GPA				
Fiction Books Read Per Year versus GPA	0.204	0.203	0.158	-0.113–0.519
Nonfiction Books Read Per Year versus GPA	0.308	0.155	0.160	-0.151–0.470
Journal Articles Read per Year versus GPA	0.288	0.156	0.145	-0.136–0.448
Intercept	0.021	16.313	6.853	2.568–30.058
$R^2 = 0.087, F_{3, 53} = 1.676$				
Literacy % versus Numeracy %	0.907	-0.017	0.143	-0.304–0.270
Intercept	0.001	28.539	4.612	19.289–37.789
$R^2 = 0.001, F_{1, 53} = 0.137$				

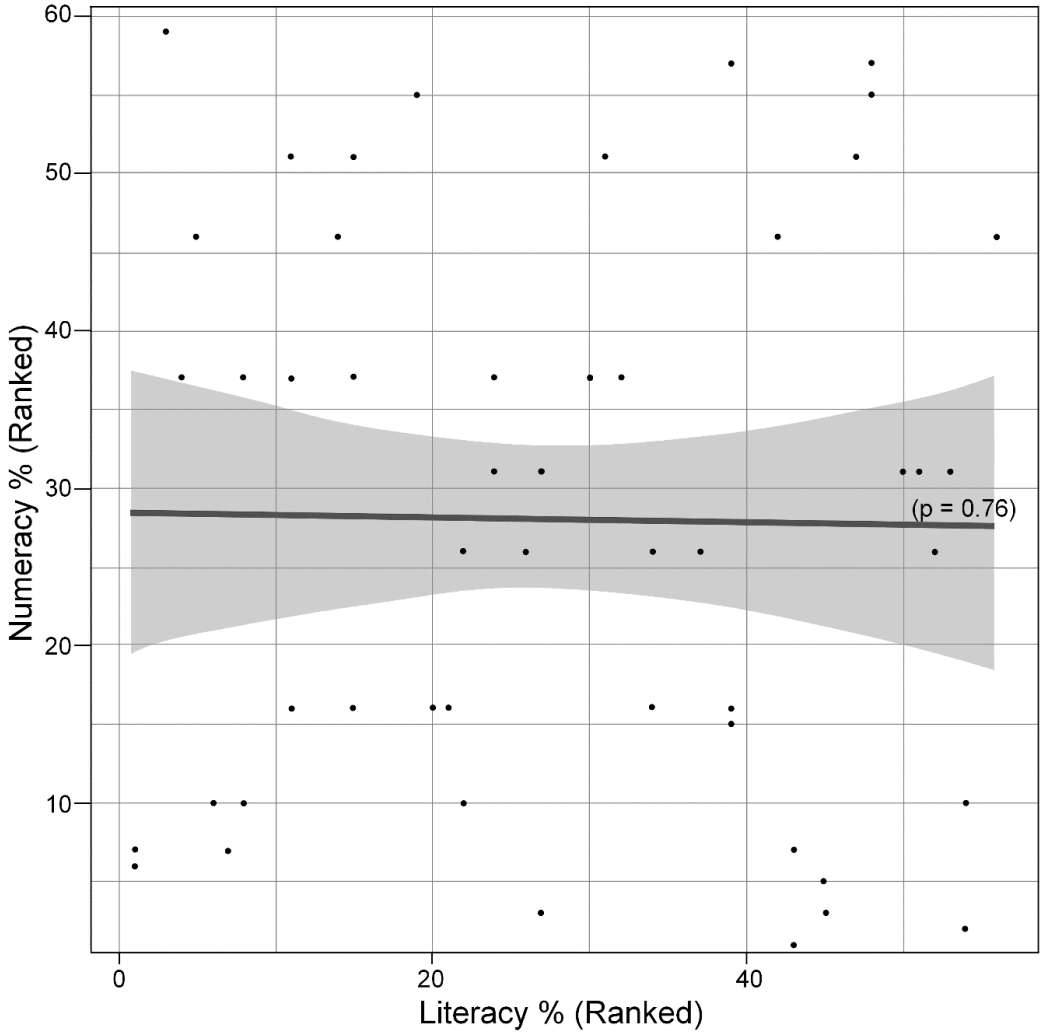

Figure 2 *The scatterplot displays numeracy percentages obtained by the students on the y-axis, and literacy percentages on the x-axis (Spearman's correlation, p = 0.756, rho = -0.043). Each point represents a student. Figure generated in RStudio and edited in Fire Alpaca.*

We also found a positive relationship between literacy skills and the number of fiction books a student reads per year. We found no relationship between literacy skill and the students' engagement with non-fiction novels and journal articles (Table 1).

Univariate tests: Spearman's correlation

We found strong evidence for a link between numeracy skills, literacy skills, and GPA (as shown in Table 2). We also found evidence for a link between literacy skills and how often a student reads fiction books (Table 2). This indicates a non-linear positive relationship between the number of fiction books a student reads in a year and their literacy skills. We found no such trend between non-fiction texts and literacy skills, nor did we find a link between student numeracy skill and student literacy skill (Figure 2).

Table 2 *Results of the Spearman tests for unranked data.*

	p-value	S	rho	CI (95%)
Literacy % versus GPA	0.030	20787	0.290	0.025–0.046
Numeracy % versus GPA	0.004	22855	0.365	0.096–0.096
Fiction Books Read Per Year versus Literacy %	0.010	16084	0.352	0.094–0.115
Non-Fiction Books Read Per Year versus Literacy %	0.400	24512	0.116	-0.156– -0.135
Journal Articles Read Per Year versus Literacy %	0.853	24159	0.026	-0.254– -0.310
Literacy % versus Numeracy %	0.756	28908	-0.043	-0.306– -0.286
Fiction Books Read Per Year versus GPA	0.134	27466	0.197	-0.860– -0.850
Nonfiction Books Read Per Year versus GPA	0.215	31726	0.161	-0.869– -0.860
Journal Articles Read Per Year versus GPA	0.164	27931	0.184	-0.100– -0.159

Principle component analysis (PCA)

Visualisation of the relationships via PCA show a positive relationship between literacy skills and numeracy skills compared to the students' GPA (Figure 3). We again detected a positive relationship between literacy skills and the number of fiction books a student reads in a year. The relationship between literacy skills and reading fiction books was stronger than the relationship between literacy skills and other forms of reading (e.g. non-fiction books and journal articles).

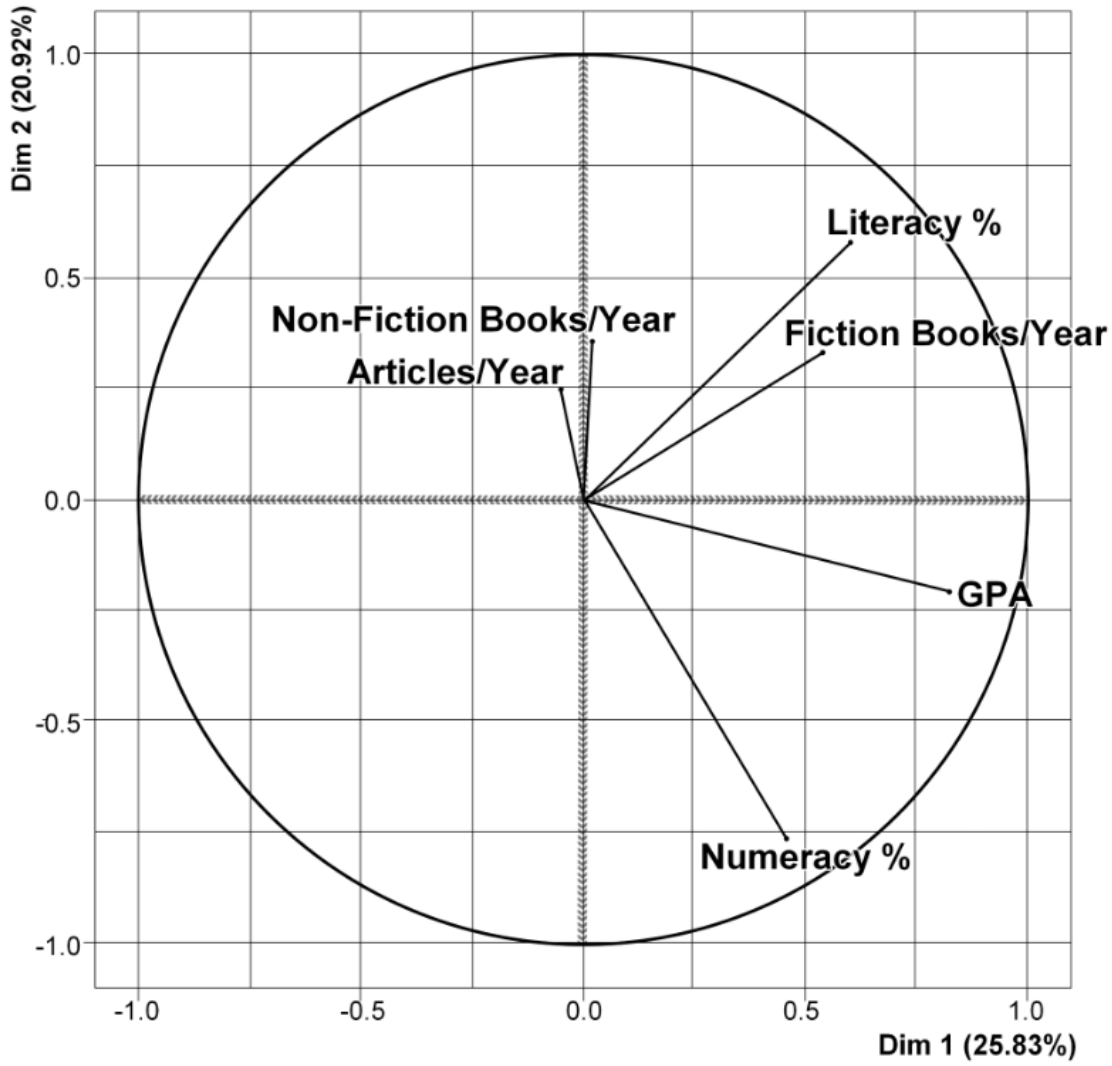

Figure 3 *A principal component analysis test showing the relationships between several variables of interest in this study. Figure generated in RStudio using the FactoMineR plug-in (Lê, Josse & Husson 2008) and edited in Fire Alpaca.*

STEM course coordinators

Both numerical analysis and visualisation of the relationship between researcher prestige and the courses they coordinate show a pattern where those with higher metrics (of publications and citations) tend to coordinate theory courses, followed by statistics courses for those with slightly lower metrics – with science communications having a clear pattern of the lowest metrics. Nevertheless, there is variation where some individuals in each of these disciplines are highly ranked relative to others in their field (see Figure 4 for a visual representation, or Table 3 for the numerical averages). Testing within institutions showed similar results (see Appendix I).

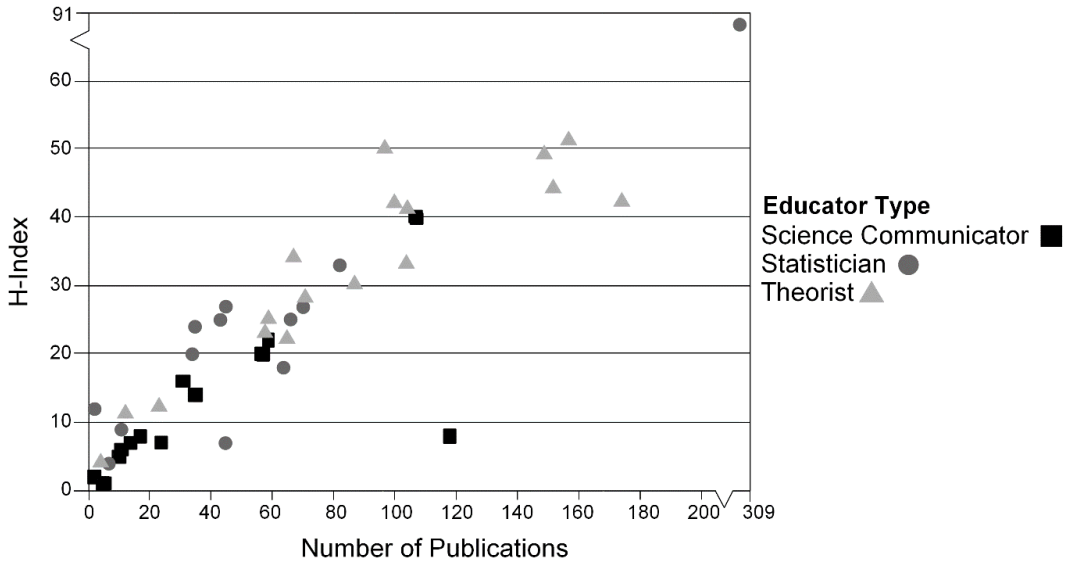

Figure 4 *A graph showing the relationship between the number of publications authored by a course coordinator and their H-index. Black squares represent course coordinators for science communication courses (biology communicators), dark grey circles represent coordinators for statistics courses (biological statisticians), and light grey triangles represent coordinators for theory courses (biological theorists). Figure generated in LibreOffice Calc and edited in Fire Alpaca.*

Table 3 *A table displaying the average h-index, number of publications, and citations gained by various course coordinators at several universities. We divided the subjects into the areas of science communication, basic ecology/biology (theory), and statistics aimed at biological science students.*

Area	h-index	Publications	Citations
Science Communication	11.17	35.92	1,114.50
Statistics	24.57	63.64	7,258.36
Theory	28.60	78.05	4,435.60

Discussion

Universities aim to equip their students with the skills that will allow them to achieve success in their academic pursuits. For biology and other science students, this has traditionally focused on developing “hard” quantitative skills (Cirino et al. 2017). However, in our study, we found that both numeracy *and* literacy play important roles in driving student success (see Figure 1).

Students seeking a stronger grasp on writing techniques to aid in their academic and career outcomes can use the linguistic tools they have been taught to improve the quality of their communication. It is therefore a useful practice for scientists to engage with written works in a way that goes beyond merely reading them, but which actually acknowledges the writing techniques the authors use (Montgomery 2003). Universities have the opportunity to take the time to give students the chance to engage with writing as a creative process. Universities might improve student learning by providing a greater focus on cultivating *both* numeracy and literacy skills in their students.

This raises the question of how universities can best teach these areas. We suggest that there is some evidence to suggest universities could attempt to teach literacy to biology students by designing courses which focus on creative writing. We found no evidence that reading scientific articles or non-fiction books has an impact on literacy skills. However, we found evidence that literacy skills can be improved by engaging in fiction. This was the case even though the texts presented to the students in the literacy test were all non-fiction. This means that it may be worth focusing on more "abstract" literacy techniques when teaching students, rather than hoping that incidental exposure to journal articles imparts these skills to the students. Of course, the association we found between engagement in fiction and literacy skill may not translate to improvements as a result of direct educational interventions, but it is worth considering, nonetheless.

In many science subjects, students are expected to pick up writing skills from the papers they read, rather than being given the opportunity to meaningfully engage with literary techniques (Ritchie et al. 2022). It is assumed – but perhaps inaccurately – that effort on the part of the student will fully compensate for a lack of education in how a student can leverage language to communicate their ideas (Thrash et al. 2010). There is a concern that this results in researchers who cannot write in compelling ways and – in turn – papers that are difficult to understand and do not fully engage the reader (Ryba et al. 2021).

In addition to non-fiction and journal articles having little effect on literacy skills, we found no evidence to suggest that there is a link between numeracy and literacy skills. This suggests that if a student is good at maths, it does not mean they can expect to be good at literacy (see Figure 2). This finding does conflict with some prior research done into the link between literacy and numeracy skills. Studies have found a positive correlation between literacy and numeracy skills. This is especially true for school-aged children and ESL speakers (Adelson, Dickinson & Cunningham

2015; Caponera, Sestito & Russo 2016; Reed, Petscher & Truckenmiller 2017; Zhu 2021). Studies have also found that university students who are skilled at language comprehension tended to display greater scientific skill (Pyburn et al. 2013) and that literacy can help develop scientific skill among elementary school students (Cervetti et al. 2012). Still, regardless of whether numeracy skill impacts literacy skill or not, both writing and numerical skills are necessary for a professional scientist, so it is important that students have the opportunity to develop skills in both areas.

Numeracy clearly contributes to student success as determined by GPA. But literacy also has a role to play. Reading non-fiction or journal articles did not appear to help students develop their literacy skills. Therefore, we cannot assume that students will pick up writing skills from the incidental reading of journal articles. In addition, there is no strong link between literacy and numeracy skills, so we cannot hope that students with strong numerical skills will develop writing skills as a side-effect. Instead, universities might invest time to develop *both* of these skills in their students. Students need to be taught literacy techniques via engagement in the writing process. Our results also suggest there may be some benefits to focusing on engagement with fiction writing specifically. Therefore, universities might put a greater emphasis on exposing biology students to writing-specific courses, allowing them to develop an affinity for the craft of writing.

However, it seems that universities do not assign their most successful researchers to subjects that develop literacy skills. We found that coordinators of “theory” subjects had the most prestigious research metrics that ranked the most prestigious, followed those coordinating statistical subjects. But science communication coordinators had the lowest ranking metrics (see Figure 4). There were outliers in each category, with several highly accomplished researchers teaching science communication, but the overall pattern is still concerning when it comes to determining the value institutions place on teaching students how to write.

The lack of attention and apparent prestige in teaching science communication seems to be at odds with a successful science career today. Skilled scientific writers can more easily share their ideas and make them more memorable by using good literary techniques. For example, techniques used in narration can be used to make ideas more meaningful to the reader. As readers are familiar with story structure, sharing ideas in a narrative style can help to focus the attention of the reader (ElShafie 2018).

In recent years there have been increasingly loud calls for scientists to share their work with non-experts in an accessible manner (Ryba, Doubleday & Connell 2019; Vergoulis et al. 2019). The

internet offers a vehicle to allow this democratisation of knowledge. Using this tool, researchers can share their knowledge with more people than ever before (Bowman & Bozich 2015). Despite these emerging opportunities, the scientific community stills struggles to communicate in understandable ways. Current scientific papers can be extremely difficult to read and miscommunication is rife even within specialised fields (Yeung, Goto & Leung 2018; Todd et al. 2010). Naturally, non-experts struggle to understand the processes and implications of science, and even experts complain about the difficulty they face in understanding their own field (Ryba et al. 2019).

If we want to address the general lack of clear and engaging scientific writing, scientists can be taught how to write effectively at a university level. It is the imperative of universities to prepare their students for meaningful careers (Woodford 1967). For biology students, this means appropriate support in the quantitative, "hard" skills that are needed for research. But more than ever, people are starting to appreciate the need for "soft" skills such as writing (Alley 1996; Jerde & Taper 2004; Montgomery 2003). Despite the name, "soft" skills are hard to master and need to be elevated as such. Despite the growing recognition of writing's importance, most biology degrees do not require that their students take a single class on writing (Ritchie et al. 2022). The assumption is that students will naturally pick up the needed skills by reading journal articles and writing essays. Our results show that this is not necessarily true.

In conclusion, as the demand for science communication grows, it is increasingly important that researchers are able to articulate their ideas with clarity. As the institutions responsible for training the next generation of researchers, universities might consider how to best to equip students with these essential communication skills. While quantitative skill remains a vital part of scientific training and should not be overlooked, there is also a strong case for developing curricula that actively support the development of clear and effective writing.

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Principal Author

Name of Principal Author (Candidate)	Mollie Hawkes Hohmann		
Contribution to the Paper	Concept and design; Analysis and interpretation; Multiple drafts; Critical Revision		
Overall percentage (%)	90%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	22/08/2025

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sean D Connell		
Contribution to the Paper	10% - Concept and design; Interpretation, drafting and proofreading; Multiple critical revisions		
Signature		Signature	22/08/2025

Chapter 6: The patterns of open-access publishing are broadly equivalent regardless of the rank of the university

Abstract

Open access publishing is a key issue in the public understanding of science, with much debate as to how to balance the demands for accessibility for both readers and writers. While open access publishing gives a wider range of readers access, publishing fees can impose a significant barrier for less resourced academics. We sampled academics from both high and low-ranking universities to see how these issues intersect. We found that academics from both categories were equally likely to publish in open access journals, though Gold Open Access was slightly more common in low-ranking institutions. While higher-ranked universities were initially more likely to publish open access this gap has since closed. While differences in university prestige are still an issue in some respects, it does not seem to affect publishing behaviour. This means researchers can make their research available in journals which both the public and less resourced researchers can readily access.

Introduction

In the modern day, there has been an increasing focus on addressing and rectifying historic areas of inequality. The involvement of the public in matters of science as well as supporting researchers of varying backgrounds is becoming an increasingly common topic of consideration for the betterment of society (Bauchner & Rivara 2022; Vergoulis et al. 2019). A common area of concern is societal inequalities when it comes to access to journal articles. To this day, many papers are hidden behind paywalls, making them inaccessible to the general public or even academics from poorly funded institutions. To address these issues, there has been an increased focus on open access publishing and a diverse field of study with multiple perspectives has emerged (Fecher & Friesike 2014). Overall, open access publishing has been slowly growing in popularity since the 1950s and rapidly increased in prevalence in the 2000s (Piwowar et al. 2018).

There are many benefits associated with open access publishing. Open access journals tend to be more accepting of a wider range of papers (Van Noorden 2013), they allow members of the public to freely access scientific literature (Frank, Foster & Pagliari 2023), and can help institutions save money on journal subscriptions (Knoche 2020). However, there are also drawbacks to this style of publishing, particularly on the writers' end. Open access publishing fees can be exorbitant, especially for poorly funded researchers (Frank, Foster & Pagliari 2023). In addition, open access

publishing models can empower predatory business practices on the part of the journal (Beall 2012).

In addition to the historic differences in access to published articles and the high expenses associated with publishing fees, there are also differences between universities. The most obvious of these are the differences in funding. The level of funding a university receives has a significant impact on its global reputation. For example, 51% percent of the variation between the top 300 universities in the Quacquarelli Symonds (QS) World University Rankings can be explained by differences in funding. The top 100 universities have double the annual budget and average expenditure per student compared to the universities in positions 101-200, and triple compared to universities in position 201-300. The calculation method used for the QS Rankings includes several components that might explain these differences such as higher staff to student ratios or academic excellence (academic excellence being calculated from research productivity which is often reliant on funding) (Benito, Gil & Romera 2019).

In turn, these rankings can impact the opportunities available to institutions and the academics that work at them. For example, university rankings can impact how willing commercial organisations are to collaborate with a university, as well as the university's ability to negotiate favourable terms (Shen, Coreynen & Huang 2022). On an individual level, employers often use educational credentials to make initial judgements of a worker's ability (Araki et al. 2016; Argue & Velema 2022; Bordón & Braga 2020). University rank has an impact on the opportunities available to researchers. As such, it is important to consider how this difference in opportunity might impact publishing opportunities.

Currently, open access and pay-walled journals are caught between an accessibility versus an affordability problem (Hunter 2019). For their part, academics tend to be in favour of the publicly accessible information provided by the open access model but find the processing fees and the potential for predatory publishing practices to be a significant barrier to publishing in these journals (Mekonnen et al. 2021; O'Hanlon, McSweeney & Stabler 2020). Recently, universities have attempted to address the issue of publishing fees by adopting 'read and publish' agreements with publishing companies. These agreements allow academics to publish in open access journals for either a reduced or entirely waived fee.

We wanted to determine which factors could influence researchers to publish in areas readily accessible to the public. Due to the controversial and complex nature of open access publishing

versus a traditional pay-walled method and the known effects of university prestige on both available funding and perception of academics (Araki et al. 2016; Benito, Gil & Romera 2019), we decided to investigate the relationship between these two factors. Pay-walled journals tend to be more selective, as they do not stand to gain monetary benefit from publishing. Therefore, they might lean towards selecting papers originating from prestigious universities (Van Noorden 2013). In addition, pay-walled journals may be biased towards research that requires extensive resources, which are more available to higher-ranking and well-funded institutions. On the other hand, the fact that researchers from high-ranking institutions tend to be more well-funded means that they might be better able to afford the – often significant – publishing costs associated with open access journals. However, we hypothesise that the selectivity of high-ranked journals will be a more significant factor and therefore academics from higher-ranking universities will publish more in pay-walled journals.

Naturally, to investigate these potential links we also needed to consider a variety of other factors which might influence publishing behaviours – both across universities and individual researchers. For example, we also investigated the impact of factors such as researcher gender, geographic region, overall temporal trends, and overall researcher impact/prestige (as determined by measures such as H-index).

Methods

We selected eighty universities from an established world-wide ranking of universities, focusing on the highest and lowest-ranking institutions in order to sample 40 highly-ranked universities and 40 lowly-ranked universities. We aimed to use this as a proxy for university funding and perceived university prestige. We excluded universities that had no available data. We also excluded non-English-speaking universities, as there are significant differences in the reach English-language journal articles get compared to non-English articles (Mur-Dueñas 2013).

Comparison of Academics

From each of the universities selected, we sampled 2-3 academics from an ecology or biology field. We focused on this field to minimise the natural differences that arise between researchers from differing fields. The researchers were selected manually from the relevant university websites. They were found through the staff directories for the resident department of ecology/biology. To help ensure roughly equivalent academic duties, only professors or associate professors were selected. We did this to gain a total of 200 academics, 100 from the low-ranking universities and 100 from the high-ranking universities.

For each of these academics, we used Scopus to obtain their H-index and Field Weighted Citation Index (FWCI). Throughout this study we used FWCI as an approximation of citation frequency. We then analysed all the papers for which the academic in question was the primary author to find: the date of their first publication, the total number of articles published, and the proportion of these articles which were published in pay-walled journals. We also made note of the gender of the academics, as it is known that this can affect an academic's career (Giakoumi et al. 2021).

We statistically analysed the above variables, comparing the means of our samples. We used a mixture of Pearson coefficient testing and one-way ANOVA. We used Pearson in cases where the variables were both continuous (for example, date of first publication and total number of articles published), and ANOVA in cases where one variable was continuous and the other was categorical (for example, author gender and total number of articles published). For the "university rank" variable, we analysed the data as both a categorical (e.g. high versus low) and continuous (e.g. 83.7 versus 30.1) variable.

We then needed to account for the fact that academics tend to change their institution over the course of their career. Therefore, it cannot be assumed that just because an academic is *currently* working at a high-ranking institution that this accurately reflects their career history. We accounted for this by collecting the rank of every university each academic had published under as a primary author (again, excluding universities that did not have an available ranking in our primary database). We then averaged these rankings for each individual and used one-way ANOVA to compare the average university rank between researchers currently working at low versus high-ranking universities.

Comparison of Institutions

'Read and Publish' agreements are an increasingly important tool for academics. We checked the websites for the academic publishing houses Elsevier, Sage, Springer, Taylor and Francis, and Wiley to see which of our sampled universities had active agreements with these publishers. We chose these publishers because they manage over 50% of all published journals (Larivière, Haustein & Mongeon 2015).

We gave each institution one point for each of these publishers they had a 'Read and Publish' agreement with (for a total of five points maximum). We also made note of the geographic region

of each of the universities sampled, as we noticed some potential regional differences while collecting the data. We used one-way ANOVA to analyse these results.

We then used the InCites database to gather further information about the different institutions' publishing habits. This database summarised all publications produced per institution from 1980 to 2024 (provided they were available on the Web of Science system). We filtered these results to select only those papers published in the research area of 'Ecology'. This provided the following data:

- Category Normalised Citation Impact – citations per paper normalised for subject, year, and document type.
- % Highly Cited Papers – percentage of publications that are in the top 1% citations for field and year, as calculated by the Essential Science Indicators.
- H-Index – the researchers' H-Index (a measure of publication frequency and citations gained) as an average across all papers listed.
- % All Open Access Documents – percentage of publications identified as Open Access.
- % Gold Documents – percentage of publications identified as Gold Open Access.
- % Green Published Documents – percentage of publications identified as Green Open Access.
- % Non-Open Access Documents – percentage of non-open access publications that are identified as not Open Access.
- % Free to Read Documents – percentage of publications identified as Free to Read.
- Country or Region
- % Q1-4 Docs – percentage of publications that were published in Q1, Q2, Q3, or Q4 journals. Used as a proxy for journal impact factor.

We also made use of the Curtin Open Knowledge Initiative (COKI) database to obtain temporal data relating to the changes in open access publishing over time. This database summarises the papers produced by each of our institutions from 2000-2023, classifying each into one of four categories and providing a percentage breakdown of these results. The four categories COKI considers are 'Publisher Open' (articles published in open access journal), 'Other Platform Open' (articles shared online, but not in a traditional journal e.g. a preprint server), 'Both' (articles both published in an open access journal and made available through non-traditional means), and 'Closed' (articles which are neither Publisher Open or Other Platform Open).

We then used one-way ANOVA testing to compare our previously selected High- and Low-ranking institutions, using the data obtained from the InCites and COKI databases.

Results

We detected a few known trends. These are detailed in Appendix I.

Table 1 and Table 2 show our results from the analysis of the Scopus data. These results offer insights into the factors that may influence the publishing habits of individual researchers such as university rank (used as a proxy for university reputation and available resources). We also analyse some possible confounding factors such as the date of their first publication as primary author, which we have used as an approximation for the length of the researcher's career. Figure 1 offers a visual comparison of the high and low-ranking universities as derived from this data.

Table 1 *The results of the Pearson chi-squared tests used to test for potential relationships between the various factors included in the Scopus data. The p-value (p), correlation coefficient (r) and 95% confidence intervals (CI) have been provided.*

Variables	**University Rank (Total Number)**	**Date of First Publication**	**Proportion of Pay-Walled Articles**
Date of First Publication	p = 0.25 *r = -0.08* *CI = -0.22–0.06*		p <0.01* *r = -0.50* *CI = -0.60– -0.39*
H-Index	p <0.01* *r = 0.36* *CI = 0.24–0.48*	p <0.01* *r = -0.41* *CI = -0.52– -0.29*	p <0.01* *r = 0.20* *CI = 0.07–0.33*
FWCI	p = 0.01* *r = 0.17* *CI = 0.03–0.30*	p = 0.03* *r = 0.16* *CI = 0.02– 0.29*	p = 0.01* *r = -0.17* *CI = -0.31– -0.04*
Total Articles Published	p = 0.41 *r = 0.06* *CI = -0.08–0.20*	p <0.01* *r = -0.36* *CI = -0.48– -0.24*	p = 0.01* *r = 0.18* *CI = 0.04–0.31*
Proportion of Pay-walled Articles	p = 0.48 *r = -0.05* *CI = -0.19–0.09*		

Table 2 *The results of the one-way ANOVAs used to detect potentially significant variation between the factors included in the Scopus data. In contrast to Table 1, this table displays categorical data (namely the gender of the researcher and whether the university was highly or lowly ranked. The p-value (p), F-value (F), and averages of each group have been provided.*

Variables	**University Rank (High versus Low)**	**Gender**
Date of First Publication	p = 0.17 *F = 1.87* *H: 1995.52, L: 1997.45*	p = 0.82 *F = 0.05* *♀: 1996.71, ♂: 1996.37*
H-Index	p <0.01* *F = 26.35* *H: 43.14, L: 30.61*	p = 0.27 *F = 1.25* *♀: 34.76, ♂: 37.88*
FWCI	p = 0.04* *F = 3.38* *H: 1.99, L: 1.69*	p = 0.90 *F = 0.02* *♀: 1.83, ♂: 1.85*
Total Articles Published	p = 0.21 *F = 1.58* *H: 17.03, L: 14.88*	p = 0.02* *F = 6.03* *♀: 12.89, ♂: 17.36*
Proportion of Pay-walled Articles	p = 0.49 *F = 0.49* *H: 0.58, L: 0.60*	p = 0.77 *F = 0.08* *♀: 0.58, ♂: 0.60*
University Rank (Total Number)		p = 0.86 *F = 0.03* *♀: 54.50, ♂: 53.66*

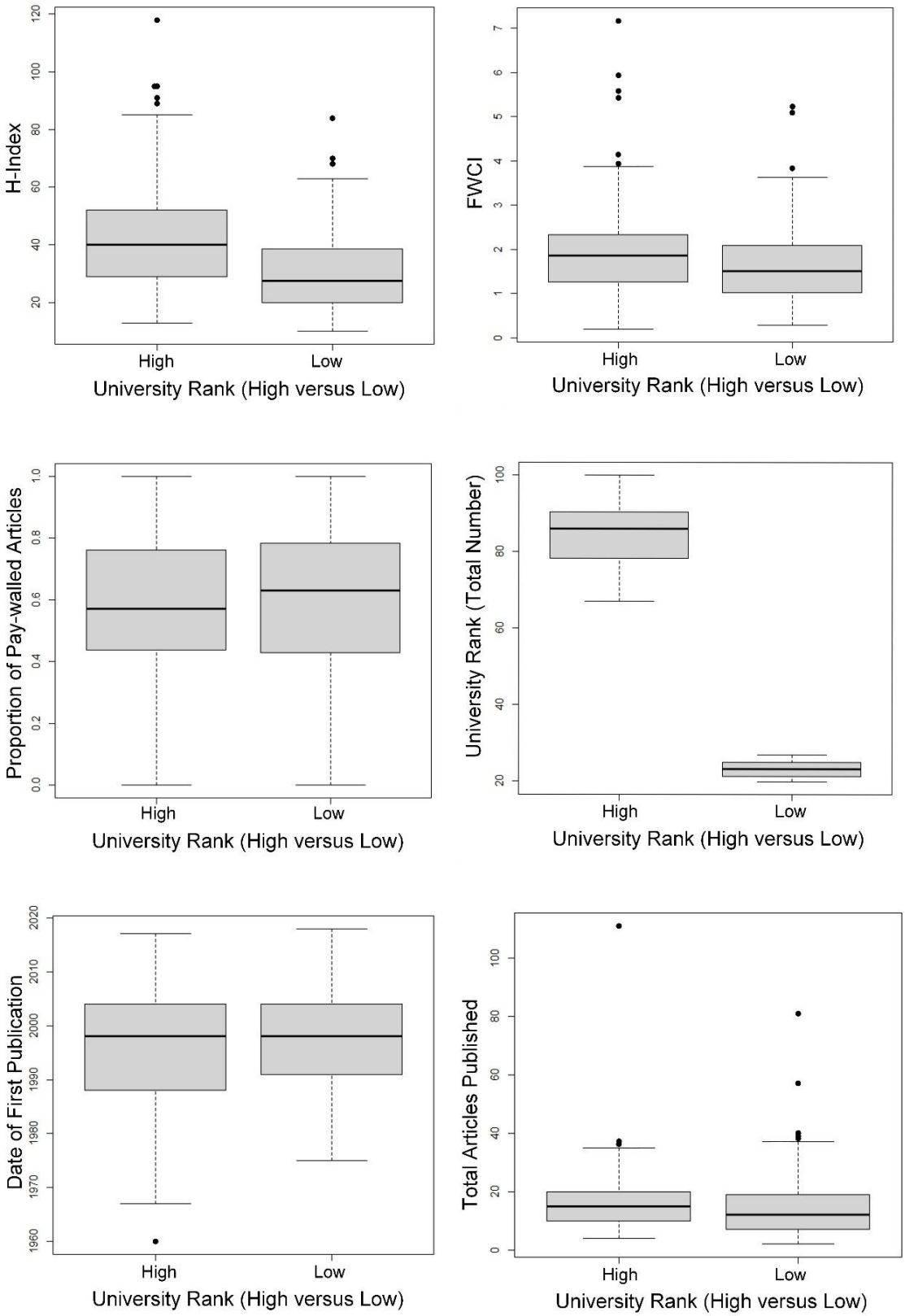

Figure 1 *An overview of the differences between high and low-ranking universities. The variables examined here are (from left to right and top to bottom): H-index, Field Weighted Citation Index (FWCI), proportion of pay-walled articles, university rank (as a total number), date of the academic's first publication as first author, and the total number of articles published.*

Table 3 displays the results of our analysis of the InCites database. This data investigates the overall patterns of publishing habits between high and low-ranking universities. As mentioned above, we hope that university rank can act as a rough proxy for university reputation and available resources, given that higher-ranked institutions often have greater funding available (Benito, Gil & Romera 2019).

Table 3 *One-way ANOVA comparisons of high and low-ranking institutions as taken from the InCites database. This data only considers articles published between 1980-2024, catalogued on the Web of Science database, within the field of ecology. Citation Impact has been normalised for paper topic.*

	p-value	F-statistic	High Rank (mean)	Low Rank (mean)
Total Documents (#)	<0.01**	31.23	2,709.48	987.65
Times Cited (#)	<0.01**	36.61	160,668.58	48,403.05
% of Documents Cited	0.88	0.03	94.43	94.36
Citation Impact (#)	<0.01**	25.86	1.77	1.48
% of Highly Cited Papers	0.10	2.79	1.22	0.98
H-Index (#)	<0.01**	40.21	159.28	85.80
% Open Access (OA) Documents	0.13	2.33	53.67	50.38
% Gold OA Documents	0.04*	4.33	13.18	15.01
% Green OA Documents	0.06	3.58	29.01	25.52
% Non-OA Documents	0.13	2.33	46.33	4.62
% Free to Read Documents	0.02*	5.99	16.43	14.22

When examining the relative “success” of scientific authors, it is important to consider gender as a potential factor, given the historic and current inequalities that exist in the academic world (Lundine 2019). This study rediscovers the known issue of male authors publishing more frequently than their female colleagues (see Table 2, or Figure 2 for a visual summary) (Madsen et al. 2022).

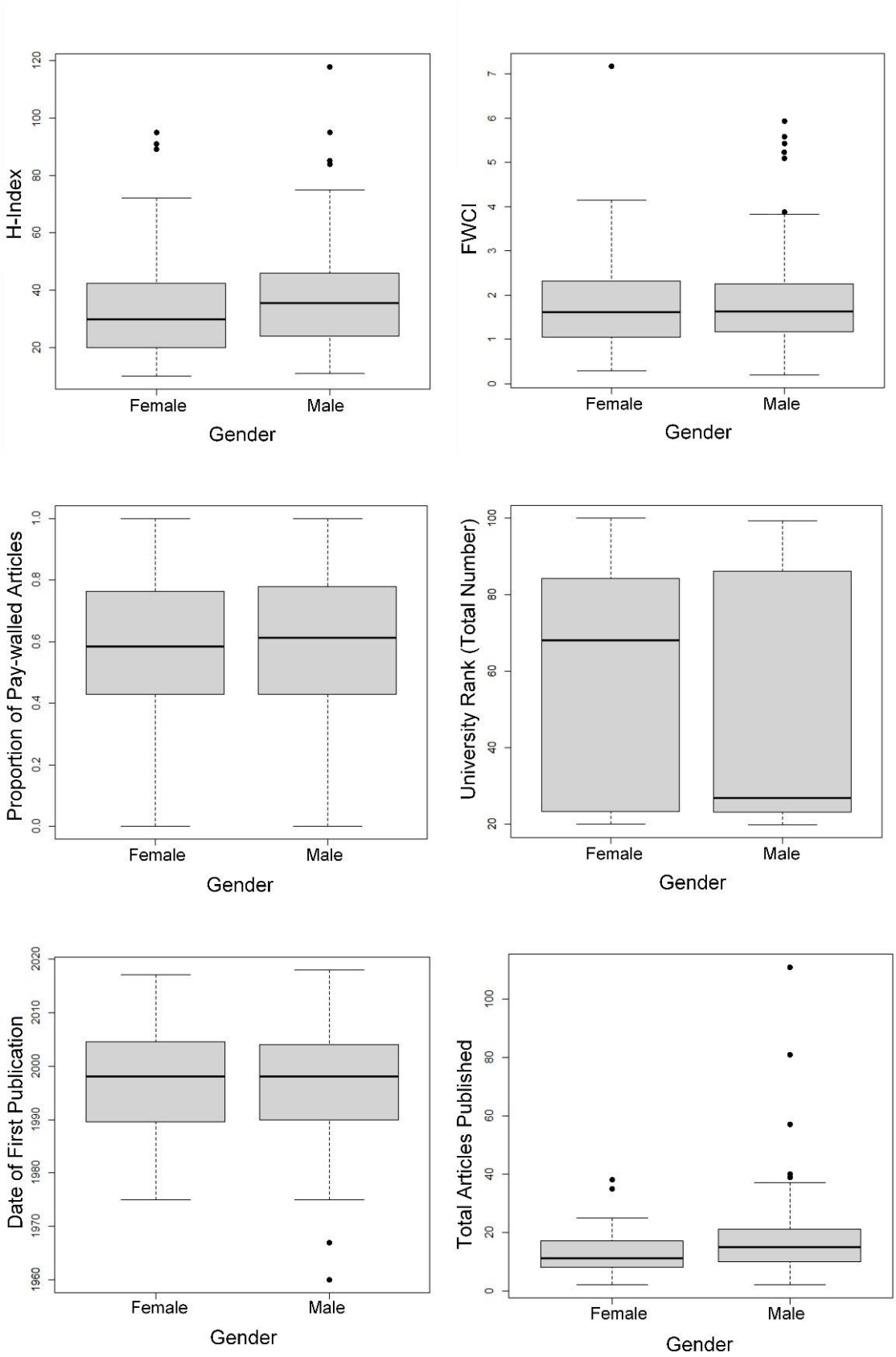

Figure 2 *An overview of the differences between male and female academics. The variables examined here are (from left to right and top to bottom): H-index, Field Weighted Citation Index (FWCI), proportion of pay-walled articles, university rank (as a total number), date of the academic's first publication as first author, and the total number of articles published.*

While this is concerning, from what we observe of our novel findings, the publication process remains fair in many other aspects. We found no effect of gender on H-index or Field Weighted Citation Impact (FWCI) indicating that – though female researchers may struggle to publish papers when compared to their male counterparts – papers that *are* published are judged relatively equally. This is true regardless of the perceived prestige of the academic's university (see Figure 3).

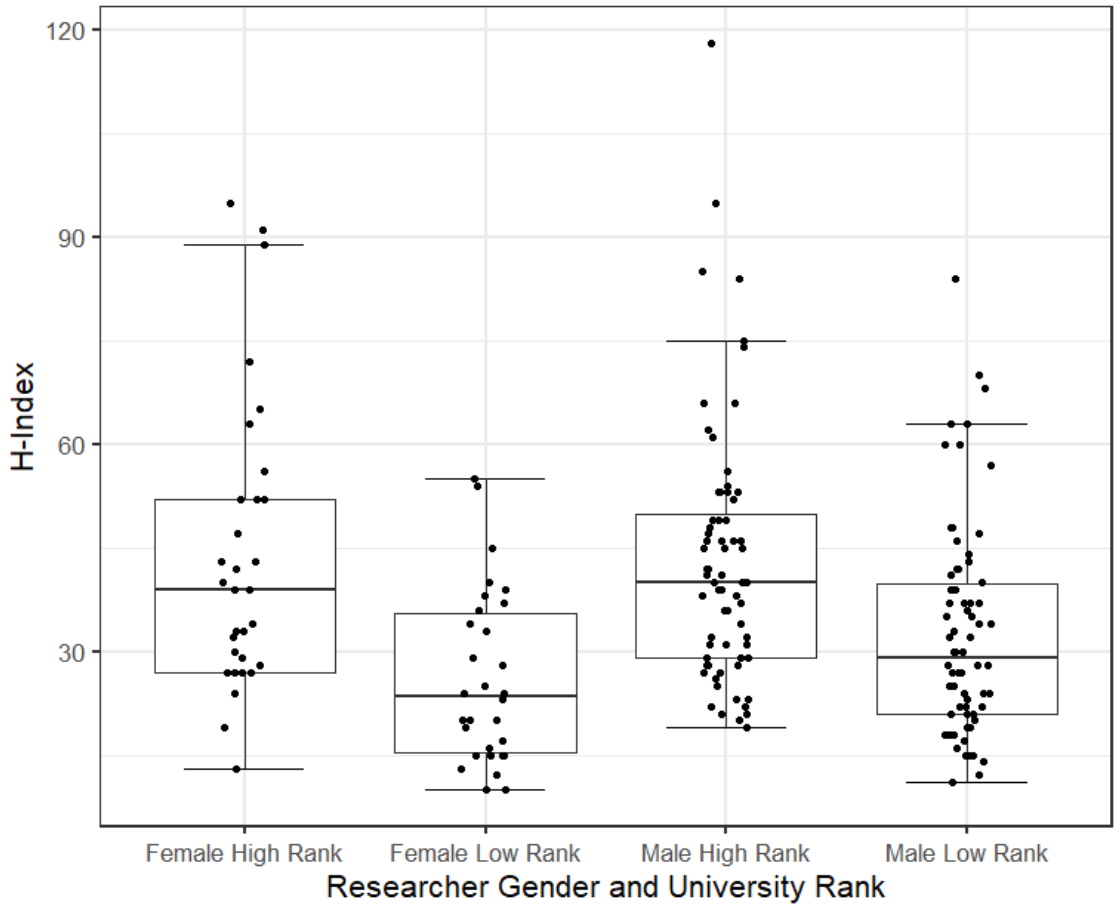

Figure 3 *The difference in H-index between women from high-ranking universities, women from low-ranking universities, men from high-ranking universities, and men from low-ranking universities. Despite some differences in distribution, there is no significant difference in H-index based on gender (one-way ANOVA, p = 0.27,* $F_{1, 199} = 1.25$*).*

We hypothesised that researchers from high-ranking universities who have access to more financial resources would preferably publish in pay-walled journals. However, we found no such trend existed. We found that there were no significant differences in publication rates in pay-walled versus open access journals between high and low-ranking universities. However, while there was no overall difference in open access publishing rates, we did detect a significant difference between high and low-ranking institutions when it came to Gold Open Access documents within the InCites

database. Gold Open Access tends to be more easily and immediately available, but also more expensive for the writer. We found that high-ranking universities published 13.18% of their articles this way, compared to 15.01% of low-ranking universities (one-way ANOVA, $p = 0.04$, $F = 4.33$, see Table 3).

Because high-ranking universities are willing to publish open access, this means that members of the public are easily able to access these high-prestige papers. However, we did find significant positive links between the H-index and FWCI of individual researchers in relation to the proportional number of pay-walled articles they published (see Table 1, or Figure 4 for a visual representation). This suggests that members of the public may struggle to access papers from highly credentialed researchers.

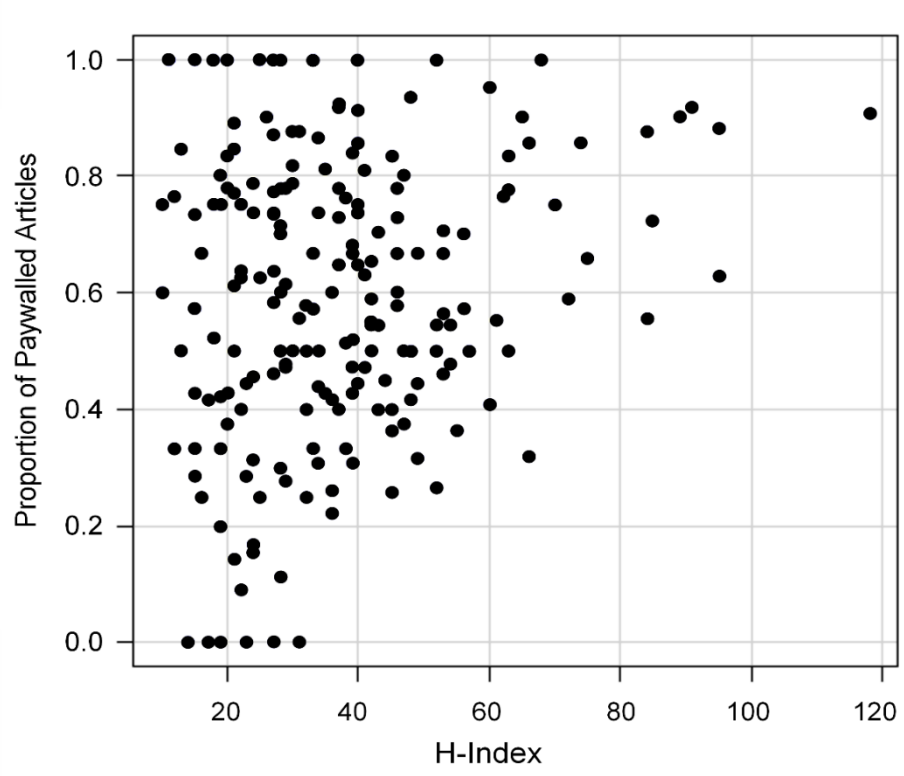

Figure 4 *H-Index of each researcher against the proportion of pay-walled articles published. Note that this positive association could be because higher-ranking academics tend to have been working longer, including prior to open access publishing becoming a widespread practice among academics.*

An explanation for the lack of a noticeable trend in open access publishing on an institutional level could be the widespread adoption of 'read and publish' agreements by both high and low-ranking universities (see Table 4). We found that, over the past 60 years, academics from all universities

have been proportionally publishing increasingly more in open access journals (see Table 1, or Figure 5 for a visual representation). On average, high-ranking institutions have signed agreements with 2.88 of the 5 major publishing houses and low-ranking institutions have signed 2.50 agreements (one-way ANOVA, $p = 0.40$, $F = 0.73$). In examining the adoption of read and publish agreements, we found that the United States has adopted these agreements at a lower rate than other areas (see Figure 6). These regional differences are significant (one-way ANOVA, $p < 0.01$, $F = 66.31$).

Table 4 *The results of correlation tests for the presence of "read and publish" agreements with several prominent publishing companies, presented as p-values. These tests were done as one-way ANOVAs. Data presented as a proportion of universities.*

University Rank	**Elsevier**	**Sage**	**Springer**	**Taylor & Francis**	**Wiley**
High	0.63	0.63	0.48	0.53	0.63
Low	0.50	0.43	0.43	0.50	0.65
P-value	*0.27*	*0.07*	*0.66*	*0.83*	*0.82*
F-Statistic	*1.26*	*3.26*	*0.20*	*0.05*	*0.05*

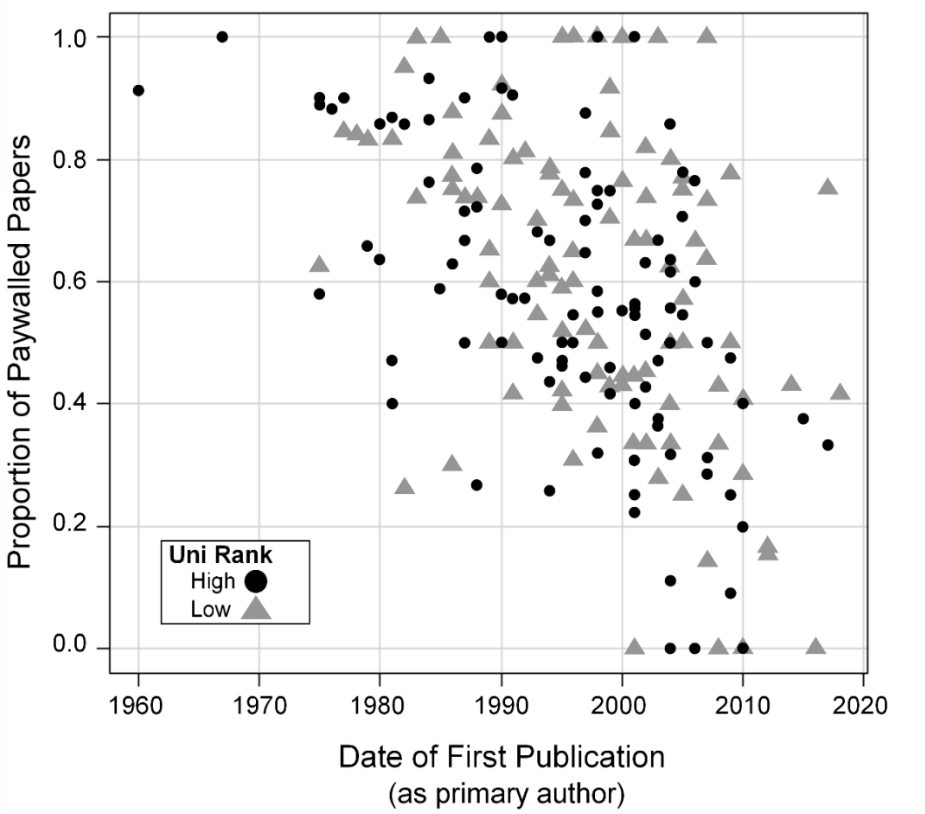

Figure 5 *A scatterplot showing the date of the academics' first publication (as primary author), versus the proportion of pay-walled papers published. The year is presented as a factor. This shows a significant decrease in the number of papers being published in pay-walled journals over time (Pearson, $p < 0.01$, $r = -0.50$). There is no difference between high (black circles) and low-ranked (grey triangles) universities.*

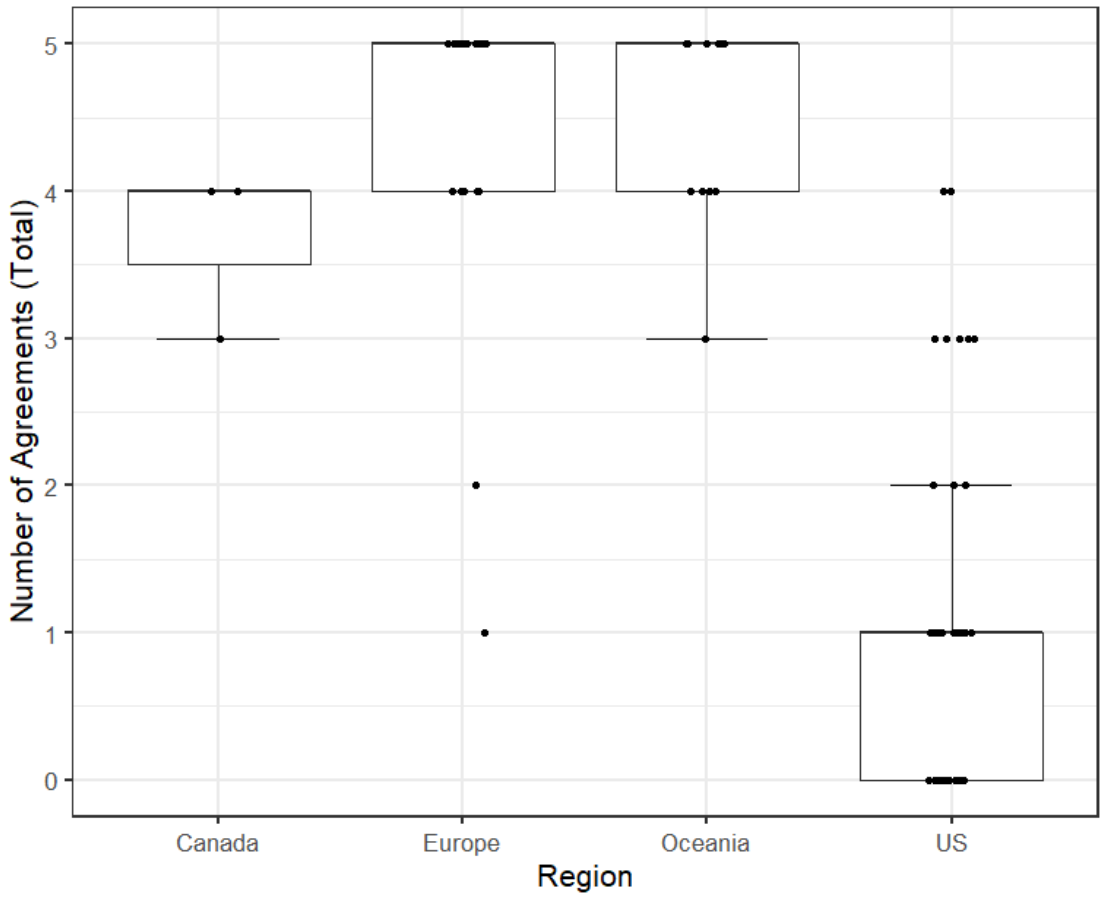

Figure 6 *The adoption of read and publish agreements by different regions. Each university was given a score from 0-5, where 0 meant they had signed no read and publish agreements with the top 5 publishers and 5 meant they have signed with all the publishers. This graph displays the different results for Canada, Europe, Oceania, and the United States.*

Academics who start their career at high-ranking universities generally worked at significantly higher-ranked universities *on average* over the course of their entire careers (see Figure 7). Even excluding their current institution from the analysis, academics who started at high-ranking institutions had an average career-wide ranking of 70.13 ±16.04, compared to academics at low-ranking institutions with an average career-wide ranking of 49.94 ±16.17. We found this difference to be significant with a p-value of <0.01 (one-way ANOVA, $F_{1, 150} = 52.35$, $\eta^2 = 0.26$). The sample size for this test was $n = 153$ due to a mixture of incomplete data for some institutions, the presence of non-university institutions, and academics who have spent their entire career at a single institution. This means that we can use the academics' current institution to draw broad conclusions about their career.

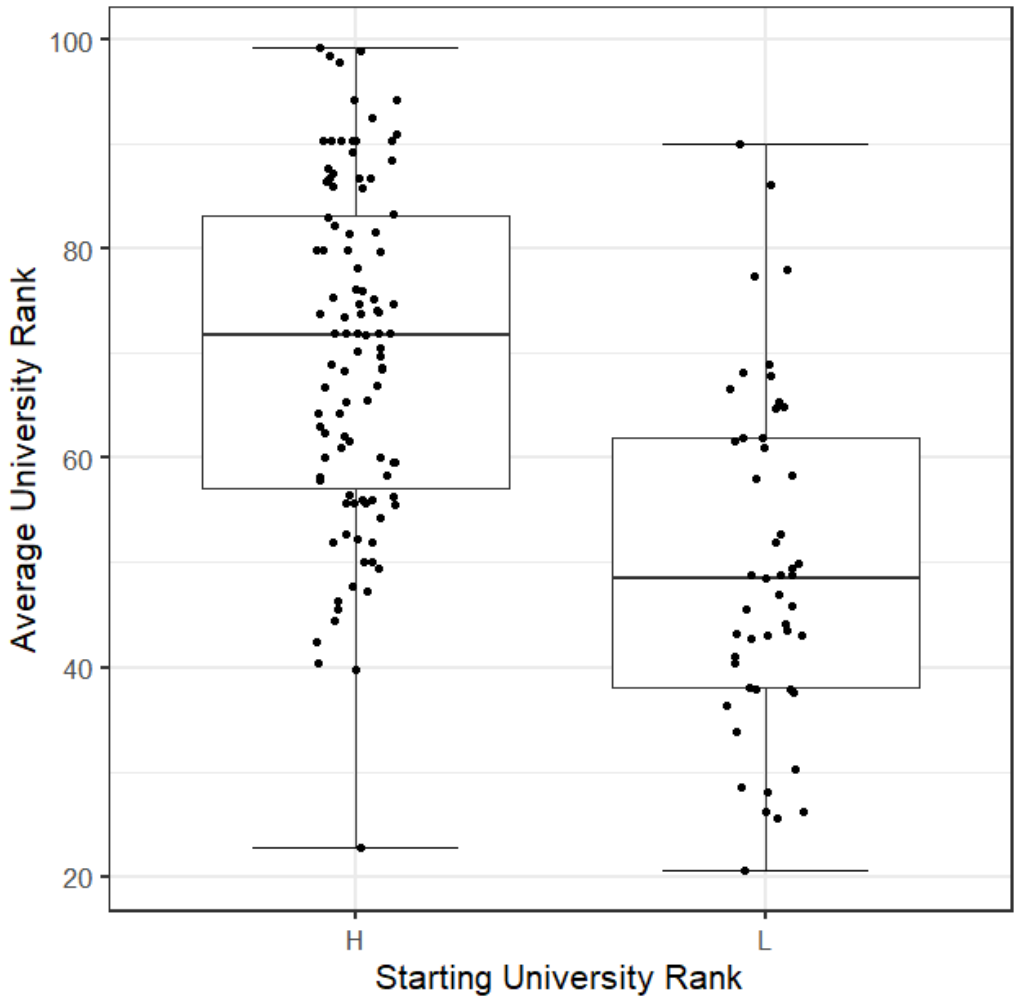

Figure 7 *The average university rank of each academic over the course of their career (excluding the institution they are currently working at), divided between academics who started their career at a low-ranking institution versus academics who started at a high-ranking institution. Academics who started at high-ranking institutions had an average career-wide ranking of 70.13, compared to academics at low-ranking institutions with an average career-wide ranking of 49.94.*

From the COKI database, we found a significant increase in the number of open access papers published since 2000 and a corresponding decrease in the number of paywalled papers (see Figure 8). Interestingly, it seems that the difference in publishing habits between high and low-ranking institutions has narrowed over time. In 2000, higher-ranked institutions were more likely to publish open access papers in comparison to lower-ranked institutions, with 14.03% compared to 10.35% of the papers produced being in open access journals (one-way ANOVA, $p < 0.01$, $F = 15.36$). But this difference has narrowed over time until it is no longer significant. In 2023, 21.45% of the papers produced by higher-ranked institutions were in open access journals compared to 21.78% in low-ranked institutions (one-way ANOVA, $p = 0.72$, $F = 0.13$). Detailed information about these trends is provided in Appendix I.

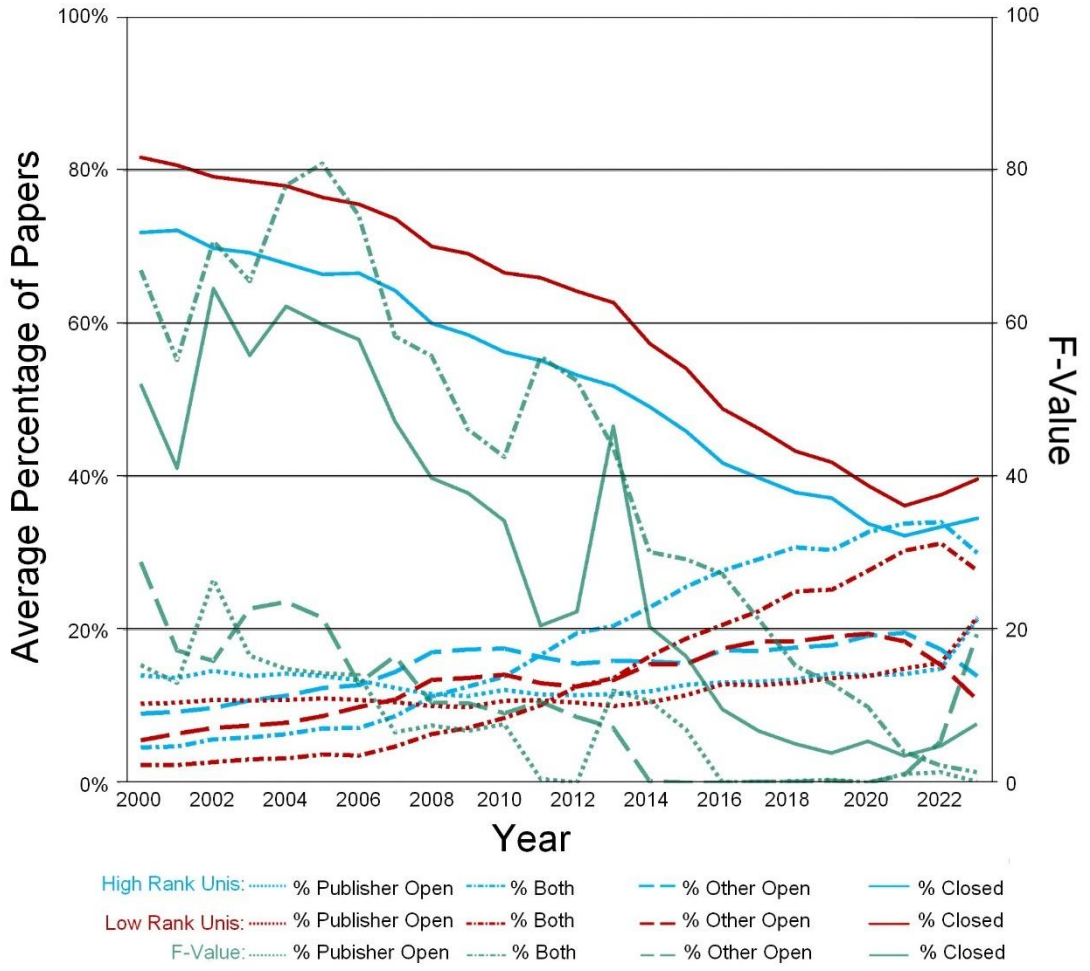

Figure 8 *Graph showing the changes in publishing patterns (years 2000-2023) between high and low ranked universities on four types of accessibility. The initially large effect of university rank on these four types has decreased over time (see F-ratios, green lines). Red lines indicate low-ranking institutions and blue lines indicate high-ranking institutions. The red and blue dotted lines (% Publisher Open) represent the average percentage of articles published in an open access journal by the institutions per year (out of all the articles published by said institution in that year). Red and blue dots-and-dashes (% Both) represent the % of articles published in an open access journal and also made available through non-traditional means, red and blue long dashes (% Other Open) represent the % of articles freely shared online but not in a traditional journal, and red and blue solid lines represent the % of closed articles.*

Discussion

As science has progressed into the modern age, the need for equality in the publishing process has become increasingly understood. Open access is just such area which scientists have recently begun to explore for these purposes. There is a diverse understanding within the scientific

community about what the study of open access publication can or should mean. The most common schools of thought include the development of the technological infrastructure used to distribute scientific research (the infrastructure school), the accessibility of the process of science to the general public (the public school), how paper impacts can be measured (the measurement school), how knowledge can be made more widely accessible (the democratic school), and how open science can benefit collaborative research (the pragmatic school) (Fecher & Friesike 2014). In this investigation we focused primarily on the democratic, pragmatic, and infrastructure school by studying the potential barriers that might prevent existing researchers from placing their research in a widely accessible location.

By focusing on supporting historically disadvantaged people, science can develop a wider understanding of the world around us. Science can develop greater insights by embracing contributions from people from all walks in life. For example, people in developing nations have historically had less of an ability to contribute to science due to discrimination and generally less wealthy institutions. But their insight in invaluable to furthering our understanding of the world, as they offer a new perspective and a deeper understanding of their local issues (Intemann 2009).

These less-advantaged researchers need to be able to access to the body of knowledge already available. But these articles have historically been hidden behind paywalls and can be inaccessible (Karlstrøm, Piro & Aksnes 2024). For example, many African universities cannot afford the journal fees needed to access the latest research (Mekonnen et al. 2021). Journals can be especially inaccessible to members of the public, who might have their own unique insights into scientific matters (Skarlatidou & Haklay 2021). These issues have led to increasing scrutiny as to the impacts of the publishing process, especially regarding open access publications.

As such, it is important to consider how equitable the publishing process is and how researchers choose to publish in open access versus pay-walled journals. We predicted that academics from high-ranking universities would be more likely to publish in the more competitive pay-walled journals, who favour the kinds of research which requires extensive resources.

However, from what we observed from our novel findings, we found that there was little impact of university rank on this publishing behaviour. While higher-ranked institutions were more likely to publish open-access during the early 2000s, this gap has narrowed over time and by the 2020s high-ranking and low-ranking institutions were publishing open access works at the same rate. There is a significant difference when it came to Gold Open Access specifically, with lower-ranking

institutions being more likely to choose this pathway. However, the overall difference in open access publishing was not significant.

This indicates that academics from low-ranking universities have equal access to the extended readership basis that comes with open access publishing (Frank, Foster & Pagliari 2023), as well as the high prestige of pay-walled journals. Whether open access publishing is beneficial to scientific writers is still a matter of great debate, however, it seems that individual academics have the freedom needed to make their own choices in the matter, regardless of the university they work for.

Interestingly, we did find significant positive links between researcher H-index and FWCI in the proportional number of pay-walled articles they published. Highly-ranked academics tended to publish more in pay-walled journals. This could indicate that it is the rank of the individual academic, rather than the rank of the university, which is the deciding factor in terms of publication choice. However, given that open access publication has become increasingly common over time (Lal & Lal 2011), it is possible that this relationship arises because higher-ranking academics tend to have been working longer, including prior to the widespread adoption of open access.

These high-ranked academics were preferentially found at higher-ranked universities, often being drawn to these institutions over the course of their career. This suggests a more complex relationship between publishing habits and institutions. These academics have an increased ability to gain citations, which can improve the perceived research productivity of their university, resulting the university gaining higher rankings (Shin & Toutkoushian 2011). This may result in a cycle whereby high-ranking institutions attract high-ranking academics who improve the standing of the institution, and this increased standing goes on to attract even more high-ranking academics. This could contribute to high-ranking institutions publishing a significantly higher percentage of papers in Q1 journals (see Appendix I). This trend may also reflect a general bias among academics to cite “top” universities in their work (which, of course, would also contribute to the aforementioned cycle).

Aside from the issues that arise because of university rank, the issue of gender is also important to consider. Male authors are known to publish more frequently in comparison to their female colleagues (Madsen et al. 2022), which we also found in our analysis. It is important that universities maintain a strong commitment to supporting female academics, as there are still clear biases in the ways in which they are treated (Schmidt 2023). However, it seems that some progress is being

made in this area. We found broad areas of equality when it comes to how female academics are judged, at least in terms of citation impact and H-index.

So, it seems the barriers imposed by both gender and university rank have little impact upon where people are able to publish. But the questions around the benefits and drawbacks of open access publishing remain. There are several benefits to open access publishing. Firstly, traditional journals which charge subscription fees to their readers have little monetary interest in publishing a wide range of papers and therefore their acceptance rate can be very low (as little as 8%) (Van Noorden 2013). Another key argument in favour of open access publishing is that, as scientific research is often in part funded by the government, placing the resulting research behind a paywall forces the taxpayer to "pay twice" for research that should be freely available to them (Frank, Foster & Pagliari 2023). Open access publishing also means that academics and their institutions can save money on subscriptions to journals (Knoche 2020).

However, despite the benefits to the readers, there are also some inequalities when it comes to open access publishing on the writers' ends. Open access journals often charge publishing fees, which may not be payable for less well-funded academics, especially academics from less wealthy institutions or regions, such as universities based in Africa (Frank, Foster & Pagliari 2023; Mekonnen et al. 2021). This is especially true for graduate researchers, who often lack the funding needed to publish in these journals (Frank, Foster & Pagliari 2023). The open access publishing model – and especially read and publish agreements – can empower predatory business practices on the part of the journal (Beall 2012; Odlyzko 2014). For example, predatory journals may spam researchers with emails soliciting papers, while failing to mention author fees (Beall 2012).

Despite the controversial nature of open-access publishing, the increase in this style of publishing is well-known in the scientific field (Lal & Lal 2011; Piwowar et al. 2018) and has been further confirmed by the results of this study. This change has given members of the public greater access to scientific resources, assisting in the democratisation of knowledge (Davis 2011). This change may be due to the widespread adoption of 'read and publish' agreements. We found that both low-ranking and high-ranking universities show widespread adoption of such agreements, which enables their academics to more easily publish open access. However, it seems that the United States lags behind in signing onto these agreements (Machovec 2019).

Conclusion

Overall, it seems that progress is being made towards supporting equality in publishing. Over the past 23 years the gaps in publishing behaviour low-ranking and high-ranking institutions have narrowed and almost disappeared. This suggests that the continued push for open access publishing and the continued adoption of read and publish agreements has been able to empower researchers to choose where it is they want to publish.

This freedom of choice is important, as there are both positives and negatives when it comes to publishing open access. While it enables more people to engage with a researcher's work, it may also place financial burdens on the researcher and can enable exploitation on the part of the publisher (Frank, Foster & Pagliari 2023). Rather than using open access solely as a method for profit, both publishers and academics have a chance to try and live up to the promise of science which is open and accessible to everyone, regardless of the resources at their disposal. But in the meantime, we can be reassured that it seems that it is not necessary to be a member of an elite university to be published in open access journals. In fact, it seems that researchers are able to freely choose where it is they wish to publish their work.

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Chapter 7: General Discussion

Being able to communicate clearly is vital for scientists. It is only through clear writing that scientists are able to effectively communicate their ideas and findings to their peers. Through this process of peer-to-peer communication the collaborative processes of science can continue to function. In addition, clear writing allows non-scientists to meaningfully engage with science. In recent years this has led many researchers to investigate the best ways for scientists to utilise language.

Throughout this thesis, I explore how scientists use scientific language in journal articles. While social media and other mass-media platforms are a valuable tool for researchers who wish to share their work, journal articles are the primary place where they share their findings and the default place for peer-to-peer communication. As such, it is important to consider the styles of academic writing which best support reader understanding and drive audience engagement, and how academics can be encouraged to write in this way.

In order to investigate these topics, I first explored how scientific writing has changed over time, providing a general background of information as well as insight into whether scientists are making an active effort to improve their writing capability (Chapter 2). I then investigated the direct impacts that writing quality can have on readers (Chapter 3). Moving on from the effect on readers, I investigated the impact writing clarity has on *writers* in the form of citations (Chapter 4). In the final two chapters, I explored how academic institutions can support their academics through writing classes (Chapter 5) and by providing opportunities to publish in open access journals (Chapter 6). Through these thesis questions, I hope to provide novel insight into the aspects which shape the current state of scientific literature and how we can best direct our efforts to produce an increasingly understandable corpus of literature.

7.1 How to Test Writing Quality

Given the extensive body of literature focused on how to write readable articles, it is clear that scientists have been considering the best methods of scientific writing for some time (Macphail 1911; Meredith 1966; Peterson 1961; Smith 1915). Scientists are increasingly likely to advocate for clear, understandable, and inspiring writing in order to aid the spread of scientific ideas (Doubleday & Connell 2017; Montgomery 2003). But what is less well understood is if this increased support for clear writing is actually reflected in scientific literature as a whole, or if it is a vocal minority of scientists who are making an effort to improve their writing.

To begin my investigation, I first needed to determine which methods for testing readability I wanted to employ. In the end, I decided to use similar methods in both Chapter 2 and Chapter 4 of this thesis, though Chapter 2 focused on temporal changes while Chapter 4 focused on citation frequency. In both of these chapters, I chose to rely on directly analysing the papers for the presence of specific writing features rather than using a mathematical model such as a readability matrix. I made this choice because – while readability matrices are useful in certain circumstances – they have a number of weaknesses and do not always accurately reflect the readability of a text (Begeny & Greene 2013; Redish 2000).

Instead of relying on these matrices, I took cues from Ryba, Doubleday, and Connell and focused my analysis on a handful of key writing components (Ryba, Doubleday & Connell 2019). In Chapter 2, the presence of these writing features was detected using a specialised computer program, whereas in Chapter 4 this analysis was done by hand. These two different methods allowed me to examine a diverse range of writing techniques across the two papers. These chapters also focused on different fields. In Chapter 4 I focused on papers in the field of environmental science, as this is my area of expertise and these papers were directly analysed by me. However, in Chapter 2 I drew on medical papers hosted on PubMed due to the longstanding and extensive nature of that database and the automated process of the analysis.

The presence of a human analyst in Chapter 4 gave me greater insight into the effect of broad language on audience engagement. While a computer could be trained to pick up on key phrases that indicate broadness, it cannot determine this element of writing with complete accuracy, at least not without an element of human verification. The same is true for visual elements. In contrast, Chapter 2 focused primarily on elements of writing which could be objectively analysed through a present/absent lens (for example, the total number of verbs and noun chunks used in the abstract). This meant that the program could analyse a number of abstracts which would be impractical for a human reader.

In contrast to Chapter 2 and 4, Chapter 3 focused on the direct effects writing clarity has on readers, rather than on the writing itself. However, the abstracts I presented the subjects within this chapter were written using the general guidelines I had used to gauge readability throughout Chapter 2 and 4. For example, the “hard” abstract employed long sentences, several hedging terms, and noun chunks. These features did indeed seem to be linked to higher levels of cognitive load – as the subjects consistently had poorer recall ability for the “hard” abstract, as well as higher self-reported levels of mental effort. However, the results of the EEG test described in Chapter 3 did not reliably

distinguish between the easy and difficult abstract. Further testing is needed to verify these preliminary results.

Another similarity between these three chapters (2, 3, and 4) was that I focused either primarily or exclusively on the abstracts of the paper. While abstracts are usually less readable than the full paper, there is a strong correlation between abstract readability and article readability which makes them a useful proxy for the paper as a whole (Plavén-Sigray et al. 2017).

7.2 The Impacts of Clear Writing on Readers

Clear and accessible writing is a crucial component of peer-reviewed articles. There is evidence that papers are more likely to be cited when they are written with an intentional focus on clear writing (Chapter 4; Sawyer, Laran & Xu 2008; Vergoulis et al. 2019; Martínez & Mammola 2021). Clear writing also allows scientists to more readily understand one another and reach out to members of the public. In contrast, unclear writing can reduce the ability of readers to understand and recall the information found in a paper (Britton et al., 1982; Ayres 2006; Wang, Fang & Gu, 2020).

From our analysis of twenty million scientific abstracts, it seems that there are some critical areas where scientists are making an effort to improve their scientific writing (Chapter 2). I found changes across the board in terms of the kinds of language scientists are employing in their papers. Specifically, I found that authors are increasingly likely to use verbs and active narration, less likely to use hedging statements, and that average sentence length has significantly reduced. The increase in active narration (Hillier, Kelly & Klinger 2016; Pinker 2014), increase in verbs (Derewianka 2012; Fairbairn 2022), and shorter sentences (Britton et al. 1982; Jeong, Roger & Washispack 2021) help to engage the reader with the text. In contrast, high levels of hedging can reduce audience engagement (Hillier, Kelly & Klinger 2016; Yao, Wei & Wang 2023). This demonstrates that there have been some positive changes in terms of how papers are being written.

However, there are some aspects of writing I analysed in Chapter 2 where I did detect some negative trends in readability over time. For example, there is an increased use of noun chunks and an over-reliance on numbers. Readers often find noun chunks (Lindsay 2013) and a large amount of numbers (Stremersch, Verniers & Verhoef 2007) difficult to understand, which reduces their ability to comprehend the key messages of the paper.

In addition – despite the different methods I used – both Chapter 2 and Chapter 4 found that sensational/motivational language is currently a popular component of scientific writing. Chapter 2 notes that this popularity is increasing over time, a finding which is supported by previous studies (Mammola 2020; Millar, Batalo & Budgell 2022; Vinkers, Tijdink & Otte 2015). Chapter 4 further linked this writing feature to increased citations. While this increase could suggest that papers are improving their writing in terms of engagement, it is easy to over-rely on this kind of language and over-hype the result of a study (Chiu, Grundy & Bero 2017).

All this assumes that these writing features do, in fact, support reader understanding. The negative trends I detected in these chapters are thought to be a matter for concern as they can prevent readers from meaningfully engaging with the text. In order to further test this assumption, I analysed the impact that "poor" versus "good" writing has on readers' ability to recall a text and their subjective experience whilst reading (Chapter 3).

I found that readers found it much easier to recall the contents of an abstract which was intentionally written with an eye for clarity. The average recall score for the "easy" abstract was 26.82 as compared to 22.82 ($p < 0.01$). In addition, the readers reported that they found the abstract easier to read, were more confident in their understanding, enjoyed the reading process more, and felt that it required less mental effort on their part. This adds further evidence to the theory that a focus on clear writing greatly benefits readers (Dahl et al. 2021; Shrank et al. 2007).

So, it is apparent that clear writing can help ensure that scientific writing can help members of the public understand and engage with scientific literature. However, this is a large-scale benefit of clear scientific writing, which may not be a pressing concern for working scientists in a day-to-day capacity. But it is not only the reader who benefits from writing which focuses on clarity and ease of understanding. In Chapter 4 I describe evidence that clear writing is strongly linked to increased citations, which – of course – are critically important for any academic scientist.

7.3 The Impacts of Clear Writing on Writers

In Chapter 4, I analysed a thousand biodiversity conservation papers from the Web of Science database to see if there was a difference in the writing style between high and low-citation papers. I found stark contrasts between these two categories. This aligns with previous studies which have investigated the relationship between readability and citations (Jeong, Rogers & Washispack 2021; Martínez & Mammola 2021; Sawyer, Laran & Xu 2008; Ryba, Doubleday & Connell 2019; Vergoulis et al. 2019). But other researchers dispute this finding (Ante 2022; Dolnicar & Chapple 2015; Lei &

Yan 2016; Stremersch, Verniers & Verhoef 2007). However, this disagreement seems to come from the wide range of fields examined (none of which are an area of biological science) and most rely on readability matrices, which I avoided in this thesis. This is not to disparage any previous work that has been done. There are countless fields to explore and methods to use and the different combinations thereof will naturally offer different insights into the relationship between readability and citations. I only want to add my own insights to the topic.

In my own study, I found that broad language was associated with increased citations, regardless of where it was used in the paper. While – as would be expected – highly cited papers are more likely to focus on a broad topic, I also found that high-citation papers are significantly more likely to use a broad title to describe a narrow topic than low-citation papers are to do the same. The use of broad language is critical to audience engagement as it enables them to quickly and easily draw connections between the paper and wider research, understand the significance of the study, and apply the results of the paper to their own field of study (Bahadoran et al. 2018; Lindsay 2011; Mensh & Kording 2017).

There are other factors which influenced citation frequency. As in Chapter 2, motivational language was a key component of my analysis and I found strong links between the use of this kind of language and citation frequency. This is certainly what researchers expect from motivational language, as can be seen by the growth of this language over time (Chapter 2; Mammola 2020; Millar, Batalo & Budgell 2022; Vinkers, Tijdink & Otte 2015). I also found that papers which use conceptual images and interpretive figure legends were more likely to be cited. This represents a relatively easy way for researchers to promote their papers. As these features – especially the latter – are not commonly used, papers that do use them can quickly "stand out".

I found strong similarities between citation frequency versus writing style and the impact factor of the journal versus writing style. This indicates that high-impact journals have an associated writing style. The origin of this style is currently unclear, but there are several potential explanations. Firstly, it may be that high-impact journals are more selective with the papers they publish. Another potential explanation is mimicry on the part of the writers. Writers may – consciously or unconsciously – attempt to mimic the writing styles of previous successful paper (Hodges & Narum 2015). I suggest mimicry as an explanation rather than the existence of an established "best practice" as there are generally limited opportunities for STEM students who wish to develop their writing skills (which I explored in more detail in Chapter 5). It is important to emphasise that I do not wish to shame any scientists who struggle to write clearly. There are generally very limited

resources available for researchers who want to learn stylistic writing, which has been a concern for decades (Woodford 1967).

7.4 How Universities Can Encourage Scientific Writing

Between the ever-changing style of scientific writing (Chapter 2), the benefit to readers from clear writing (Chapter 3), and the links between clear writing and publishing success (Chapter 4), it seems like researchers with well-developed writing skills have a greater chance to be successful in their careers. As the institutions responsible for educating the next generation of researchers, universities have the perfect opportunity to help students develop these skills. However, it seems like these opportunities are not being taken, with many researchers graduating without any formal writing training (Ritchie et al. 2022). Instead, many science degrees focus overwhelmingly on "hard" quantitative skills. In contrast, I wanted to determine if a focus on "soft" skills such as writing can help science students find success in other areas of their academic work.

In Chapter 5, I found that both numeracy and literacy skills are important drivers of biological science student success. Numeracy very clearly contributed to student success, but literacy also had a significant role to play. Students with a stronger grasp on writing techniques can use these to improve the general quality of their papers. Therefore, it is a useful practice for scientists to engage with written works in a way that goes beyond passive reading and instead actively engages with the writing techniques the authors use (Montgomery 2003).

I suggest that universities consider the potential benefits of teaching literacy to biology students by designing courses that focus on creative writing. I specifically suggest creative writing because I found no evidence that reading scientific articles on non-fiction books had an impact on literacy skills, however, I did find some evidence that strong literacy skills are associated with engagement in fiction. This was true even though the texts presented to the students were all non-fiction (Chapter 5). This suggests it may be worth focusing on more "abstract" literary techniques when teaching students, rather than hoping incidental exposure to journal articles provides all the knowledge students need. This is especially true if we hope to "shift" the general state of scientific writing in a positive direction. If we accept that there are places where the current style scientific writing could be improved, then we need to take action to create these improvements. Allowing students to learn through exposure will mean that they will also learn the poor writing habits currently extent in scientific literature.

There is also strong support among students for writing courses which can help them actively develop their skills (Jalongo, Boyer & Ebbeck 2014). The exact nature of these potential courses should be determined by those with more expertise in the field of education. However, engagement with fiction may help students learn a wider variety of writing techniques and open their minds to the potential language has to connect with and inspire people.

In addition to non-fiction and journal articles having little effect on literacy skills, I found no evidence to suggest that there is a link between numeracy and literacy skills. This suggests that if a student is good at maths, it does not mean we can expect them to also be good at literacy. However, it should be reemphasised that this finding conflicts with some prior research (Adelson, Dickinson & Cunningham 2015; Caponera, Sestito & Russo 2016; Reed, Petscher & Truckenmiller 2017; Zhu 2021). Still, regardless of whether numeracy imparts literacy skill or not, both writing and numerical skills are necessary for a professional scientist, so it is important that students have the opportunity to develop skills in both of these areas.

Despite the importance of clear writing for supporting reader understanding (Chapter 3) and the calls among students for help developing their writing skills (Jalongo, Boyer & Ebbeck 2014), it seems that universities are not assigning their most successful researchers to science communication subjects. So, it is little wonder that scientific writing tends to be needlessly dense when universities do not encourage engagement in the field of creative writing. I found that coordinators of “theory” subjects had the highest research metrics on average, followed by those coordinating statistical subjects. Science communication coordinators had the lowest ranking metrics on average (Chapter 5). The lack of attention and perceived prestige in teaching science communication seems to be at odds with a successful science career today. Quantitative skills will, of course, always be important for researchers and I am certainty not suggesting that these areas should be neglected. However, universities could also take the time to develop curricula that give students the support they need to develop their writing skills.

But it is not only students who need support on their writing journey. I wanted to investigate how universities support their researchers at the publishing stage. Given that highly successful academics are often found at high-ranking institutions (Chapter 6), I was interested to see if the rank of an institution has an impact on whether papers are published in open-access or pay-walled journals.

As I have continually discussed throughout this thesis, easy access to well-written academic papers is important for both scientists and members of the public. In many cases these papers are still hidden behind a paywall, but this has been changing since the early 2000s. I investigated some of the potential causes of this change, paying particular attention to see if wealthy, highly-regarded institutions had a particular advantage when it came to making articles freely available. No matter how knowledgeable a researcher is about the publishing process, publishing can be an expensive prospect. This is especially true for early-career researchers from poorly-funded institutions who are in a weaker financial position when it comes to affording the publishing fees associated with high-ranking journals (Benito, Gil & Romera 2019).

I conducted an investigation into which universities are publishing open access papers, drawing on the Scopus, worldwide university rankings, InCites, and Curtin Open Knowledge Initiative (COKI) databases (Chapter 6). From what I observed of my novel findings, there was little impact of university rank on publishing behaviour. While higher-ranked institutions were more likely to publish open-access during the early 2000s, this gap has narrowed over time and by the 2020s high-ranking and low-ranking institutions were publishing open access at the same rate.

Interestingly, I found significant positive links between researcher H-index/citation impact and the proportional number of pay-walled articles they published. This could indicate that it is the rank of the individual academic, rather than the rank of the university, which is the deciding factor in terms of publishing choice. However, given that open access publication has become increasingly common over time, it is possible that this relationship arises because higher-ranking academics tend to have been working longer, including prior to the widespread adoption of open access.

The shift towards open access publishing may be due to the widespread adoption of 'read and publish' agreements. I found that both low-ranking and high-ranking universities have adopted these kinds of agreements across the board, which enables their academics to more easily publish open access. This would also explain why the United States lags behind in terms of publishing open access (Chapter 6), as the US has been slow to adopt these agreements due to the size and bureaucratic diversity of the country (Machovec 2019).

7.5 The Impact of Gender

Within most fields of science, it is known that there are clear biases in the ways female researchers are treated in comparison with their male colleagues (Madsen et al. 2022; Schmidt 2023). For example, in certain fields such as ecology there are long lags between doctoral education and

faculty appointments (Larivière, Haustein & Mongeon 2015). Despite this, I generally found broad patterns of equality when it came to the gender of the authors of a paper. In Chapter 4, I found no significant relationship between the gender of the primary authors and the number of citations a paper receives. Likewise, I found that female authors had equivalent citation impacts and H-indices to their male colleagues (Chapter 6).

However, I did find that papers with a higher proportion of female authors were cited slightly less frequently than papers with a male-majority authorship team (Chapter 4). In addition, female authors accounted for only around a third of authors overall. I also found that female authors published less than their male colleagues, a result which has been supported by previous research into the topic (Chapter 6) (Madsen at al. 2022). However, the fact that I found no significant effects of gender on H-index indicates that – though female authors may struggle to get papers published – papers that do manage to make it through the publishing process are judged relatively equally.

Overall, the findings of my thesis indicate that there are still specific struggles which exist only for female authors. However, this effect is perhaps not as pronounced as it was a few years ago, given the broad equality between citation impact and H-index I detected, as well as the overall lack of difference in publishing habits between male and female researchers.

7.6 The Advent of Artificial Intelligence

In the years I took to write my thesis, artificial intelligence (AI) has become an increasingly widespread tool. In the context of my thesis, what is most interesting is the capacity for AI tools to both write and summarise academic texts. While I was a few years too early to explore the potential impacts of this technology, I think it is important to at least mention this topic in this thesis.

One of the most obvious benefits of AI tools are the assistance they can provide to scientific writers in terms of helping them to refine their writing. For example, tools such as ChatGPT can be leveraged to suggest rewrites for the sake of clarity and conciseness (Gruda 2024). This not only reduces mental burden on the part of the scientist but helps to ensure an end product which is more reader-friendly (Khera et al. 2025). Even if not used in the writing process, AI tools can also assist readers by summarising complex scientific texts into easily understandable language (Rojas 2024). This can not only benefit members of the general public, but also scientists who do not specialise in the field in question, allowing for greater interdisciplinary understanding (Mishra, Henriksen & Woo 2026).

Of course, there are still potential issues – some of them major – when it comes to the use of AI in scientific papers. I am reminded of the infamous Frontiers paper which included nonsensical figures generated through the AI software Midjourney (Guo, Dong, & Hao 2024). This paper is, of course, an outlier in terms of poor usage of this kind of software. However, I think this case still demonstrates some key points. It shows that some scientists are willing to use this technology without double-checking the generated results to ensure they are accurate. It shows that these papers can still be accepted for publication. As the capabilities of AI advances, it may well be the case that the kinds of errors seen in this paper no longer occur. However, it could also be the case that AI merely becomes better at avoiding *obvious* mistakes. This could have an especially profound effect on non-expert readers, who cannot be reasonably expected to pick up on minor errors in field-specific contexts.

Even if we assume that the technology will develop to the point where no errors can be made, this does not mean the technology is unassailable. As I posit in this thesis (especially in Chapter 2), there are still issues in the way current scientific papers are written. This means that if AIs are trained off existing scientific papers, they will incorporate these flaws into their writing styles. In addition, if papers written using AI become the dominant style of paper this could have direct negative impacts on the quality of AI. Let's say an AI is programmed to base its writing style on, for example, papers published in Nature. If the majority of papers published in Nature start using this tool, this can result in a negative feedback loop whereby the increasing lack of human-generated content "fed" into the AI results in a decline in the quality of the AI's writing ability (Wenger 2024).
It should also be noted that there are concerns about how AI intersects with the issue of plagiarism. It is very difficult to determine where AI tools such as ChatGPT draw their knowledge from. As such, it is easy for people who use these tools to accidentally use someone else's work without knowing (Dien 2023).

Overall, I believe there are definitely some use-cases where the adoption of AI technology could have profound positive effects on the general writing quality of scientific papers. However, I do think this technology should be approached with caution. For example, if a scientist chooses to use an AI to help improve the clarity of their writing, they should manually approve each suggested change to ensure that no errors are introduced to the paper. The questions of how this should be enforced and what specific ethical standards should be introduced to govern AI technology lie outside the scope of this thesis but are nonetheless important to consider.

Finally, on a personal note, I admit that I am somewhat concerned that a widespread adoption of AI for the purposes of scientific writing would minimise the value of the craft. I believe that scientific writing should be treated as an artform, just as poetry or filmmaking is. So, if one agrees that AI cannot write a meaningful poem, why can it be trusted to write a meaningful paper? Of course, the purposes and techniques used in poetry and scientific writing are very different, but the potential for person-to-person connection remains the same.

7.7 Limitations and Future Research

There are a few avenues of scientific enquiry which I would like to suggest for future research. It should go without saying that scientific research can usually benefit from repeated tests and larger datasets. In this thesis, this is especially true for Chapter 3 and Chapter 6. Scaling up these tests would allow more reliable and insightful conclusions to be drawn. These tests could also include a greater focus on how certain demographics of readers might differ in terms of how they engage with papers. This would be especially beneficial for Chapter 5 given the diverse nature of learning styles.

I would be interested in seeing a more robust "rubric" for measuring the quality of scientific writing. As I have discussed previously, readability matrices can be unreliable and an EEG is impractical in many cases. It may be useful, therefore, to develop a more comprehensive rubric. As opposed to a readability matrix which generally only accounts for vocabulary and sentence length, I envision a more extensive version which accounts for a wider range of language features – such as sensational language and active verbs. This would have the advantage of being more insightful and multivariate than a typical matrix, but (as opposed to human testing) could be automated to allow for very large sample sizes. In essence, it would help find a balanced medium between the methods used in Chapter 2 and Chapter 4 of this thesis.

Such a model could even apply different weightings to writing features depending on the importance of the feature in question. However, choosing these weightings would likely require further direct testing of the impact on readers, likely with the aid of an EEG or similar device. This would be an extensive experiment would likely require significant funding but could provide incredibly interesting insights into what kind of writing people typically respond to. I envision a technique similar to the one I used in Chapter 3, but with a larger pool of abstracts. While a control abstract would likely be needed to provide a baseline for each subject, the second abstract provided to each subject would be randomly selected and employ a different combination of writing techniques. For example, one abstract may have no noun chunks and many acronyms, whereas another may have no acronyms

but many noun chunks. From this, we can see which combination of writing techniques generally results in the best recall score and audience feedback.

Another avenue for exploration would be a continuation of Chapter 4, with a focus on trying to untangle the causal relationships between citation frequency, journal impact factor, and writing style. While we can assume that citation frequency is – in part – a result of journal impact factor, the scope of this thesis does not explain what causes the clear association between impact factor and writing quality. A deeper, multivariate analysis examining this question would provide some deep insights into that chapter of my thesis. In addition, this study could provide an ideal opportunity to investigate additional variables which may influence citation rates such as topic of research and promotion on social media.

As mentioned above, artificial intelligence (AI) has become increasingly prevalent in all aspects of life in the last few years. As such, exploring the impacts that AI may have on the writing and reading of scientific papers would be an obvious avenue for future research. For example, future researchers might investigate the capacity for AI to help guide researchers towards more reader-friendly language. However, such investigations should also consider the likelihood of these kinds of tools introducing inaccuracies into scientific papers. This could be done by developing/training a tool to reword existing scientific papers, then manually examining the re-worded papers to see how often information is altered, added, or deleted. This technique could also be used to compare multiple different AI tools to see which ones are the most reliable in terms of maintaining the original information and intention of a text.

Finally – as mentioned in Chapter 3 – the EEG component of this thesis requires further testing in order to verify and properly investigate our initial results. The authors of this chapter are currently discussing the best path forward in order to conduct these tests.

7.8 Ethical Reflection

For the chapters which involved working directly with people (namely Chapter 3 and Chapter 5) appropriate ethical approval was granted by the University of Adelaide. Chapter 2 focused on data gathered automatically via a computer program and as such no individual data was handled by the researchers involved.

Chapters 4 and 6 differ from the above, as I both gathered and directly handled identifiable information. In the case of Chapter 4, this was mostly incidental due to examining specific scientific

articles. The identities of the authors of these papers was a component of the investigation in terms of testing the effect of author gender on publishing prestige and regularity. However, the specific papers and the authors thereof was only made available internally to myself and my primary supervisor.

Chapter 6 was somewhat more personal, as it focused on specific researchers and their careers. However, the data collected was all publicly available. Even so, the researchers, their home university, and the specific database used to establish university rankings were kept anonymous in the thesis to minimise the possibility of identification (as in Chapter 4).

I see minimal ethical concerns with the studies conducted throughout this thesis. The data collected was either granted specific approval by an ethics committee, was non-identifiable, or publicly accessible through a combination of university websites and public academic databases. In the latter case, the specifics of the data collected (e.g. the names of the researchers being analysed) was kept internal regardless, thus minimising the chance of reidentification.

7.9 Conclusion

Through this thesis I have validated the suspicion that the readability of scientific writing is changing over time. Some of these changes such as the use of active narration bode well for the future of scientific writing. However, in some areas writers continue to rely on dense prose, as can be seen with the increasingly reliance on writing features such as noun chunks (Chapter 2). However, the clear changes in writing style show that scientists are willing and able to change the way they express their ideas.

This is important, as clear writing can help reduce cognitive load on the reader (Chapter 3). In turn, this helps them remember and understand the content of a scientific paper. But not only does clear writing benefit readers, it can also benefit the authors themselves as clear writing – and in particular, providing broad context to the readers – is linked to increased citations (Chapter 4).

But it is not enough to continue to advocate for clear writing, despite its clear benefits. We also need to give scientists the opportunity to develop their writing skills. Universities generally lack courses which teach STEM students how to write well. This is despite the fact that both numeracy *and* literacy have a positive impact on student success (Chapter 5). It seems that many courses are content to allow their students to learn how to write through passive exposure to academic

texts, despite the fact that improved literacy is linked only to engagement with fiction texts. As such, I advocate for universities to actively support students in improving their literacy skills.

Another area where universities are commonly called on to support their researchers in terms of making their research more accessible is by helping them publish open access. It seems like these efforts have been successful, as the differences in publishing patterns between low-ranking and high-ranking universities has narrowed into insignificance in recent years (Chapter 6). So as with the first chapter, we once again see that efforts to improve the state of scientific writing have had measurable positive effects. I advocate for these efforts to continue, until we can break away from the stale scientific writing of the past, towards a future where papers are written to be read.

7.10 References

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Appendices

Chapter 3: Appendix I

Here we report the preliminary findings of the electroencephalograph (EEG) test mentioned in the main body of this chapter. Further research is required in order to further investigate these initial results.

EEG is an increasingly common method of measuring mental burden. This technology records the underlying electrical brain activity of a subject. Through this technology we can obtain a measure of mental burden which is more direct than self-reporting or recall. Previous studies have found that the strength of alpha and theta brainwaves change in response to the relative difficulty of the task given to the subject, i.e. how much mental burden that subject is under. These changes tend to be especially noticeable within the frontal and parietal regions of the brain (Al-Samarraie et al. 2019; Gevins et al. 1997; Sinha et al. 2019).

The EEG recorder used for this experiment was a 31-channel BrainVision Recorder (Version 1.25.0001). The amplifier was an actiCHamp Base Unit (5002). The sampling interval was set to 2000 μs and the sampling rate was set to 500 Hz. No software filters were used. The impedance measurement range was 10-50 kOhm. Subjects were fitted with an actiCAP Snap electrode cap with a standard 32-electrode arrangement and electrode Fp2 acting as our reference electrode. Electrolyte gel was applied to the scalp at each electrode point.

The spectral power (brain activity) recorded from the EEG test were cleaned using a custom MATLAB program created in version 25.1 (MathWorks 2022). This program removed noise from the recorded results (e.g. removed recorded eye-blinks) and re-calculated the results to make them relative to each subject's resting baseline brain activity in order to control for natural variation between subjects.

The EEG data was analysed using linear mixed models in IBM SPSS Statistics, version 29.0.2.0 (IBM Corporation 2017). We examined variation in the theta/alpha ratio of the participants, given the well-known association between mental burden and these varieties of brainwave (Gevins & Smith 2000; Sinha et al. 2019). We chose to focus our analysis on key electrodes which previous research has shown have interpretive value for exploring mental burden – these being taken from the frontal and parietal region of the brain (Gevins & Smith 2000; Scharinger 2024). Individual participants were included as a random intercept. The spectral power of key electrodes (Gevins &

Smith 2000; Scharinger 2024) acted as our dependent variable, while our Likert results and the abstract difficulty acted as our fixed factors.

Table 1. *P-values from our linear mixed models of the spectral power of key diodes (Gevins & Smith 2000; Scharinger 2024) acts as the dependent variable. For each key diode we report the theta/alpha ratio (θ/α). Fixed factors present in our model are: reading ease (how easy the subjects thought the abstract was to understand), confidence (how confident the subjects were in their understanding), enjoyment (how enjoyable the subjects found the abstract), mental effort (how much mental effort the subjects spent on reading the abstract), and abstract (whether the abstract was easy or hard).*

Diode	**Fz (θ/α)**	**F3 (θ/α)**	**F4 (θ/α)**	**Pz (θ/α)**	**P3 (θ/α)**	**P4 (θ/α)**
Reading Ease	0.00	0.00	0.00	0.04	0.03	0.01
Confidence	0.01	0.00	0.01	0.04	0.01	0.00
Enjoyment	0.00	0.00	0.00	0.25	0.67	0.24
Mental Effort	0.00	0.00	0.04	0.64	0.46	0.49
Abstract	0.75	0.73	0.46	0.21	0.29	0.12

These results seem to indicate an association between spectral power from self-reported Likert results around reading ease, confidence, enjoyment, and mental effort. These responses were especially pronounced within the frontal regions of the brain, whereas the responses from parietal regions were less consistent (Gevins et al. 1997). This indicates that an EEG may be useful tool for verifying and measuring audience attitudes towards a piece of writing.

However, we found little evidence that an EEG can reliably detect the overall difficulty of a piece of writing. This is consistent with some previous research which found that the links between alpha and theta spectral power and mental burden can be unclear (Scharinger 2024). In addition, our "hard" abstract – while difficult to comprehend – was not so difficult that it was outside the bonds of what could be expected in published scientific writing. For example, the grammar and spelling were correct. Likewise, our test did not consider additional post-hoc control such as event-related brain potential due to the relatively small sample size (Baretta et al. 2012).

The difference in result when it came to measuring spectral power against abstract difficulty and spectral power against the Likert scale results may also be a reflection of the varying scientific

experience among our subjects. For example, someone who is familiar with scientific writing would likely struggle less in comprehending a difficult abstract and as such display a lesser level of mental burden compared to someone who is unfamiliar with scientific writing. Therefore, the audience attitudes towards the text indicated by the Likert results may well be a more appropriate measurement to use in an EEG study as opposed to a direct comparison of writing style.

These issues may be why the results we gained from this test are currently inconclusive (see Table 2). Currently our results show unclear directionality. We hope that additional sampling in the future can help in clarifying the nature of this relationship.

Table 2. *Additional statistics from the above EEG tests, as provided by our linear mixed model.*

Estimates of Fixed Effects: Intercept							
	Estimate	Standard Error	Degrees of Freedom	t	Significance	95% CI: Lower	95% CI: Upper
Fz	-4.31	3.16	42	-1.36	0.18	-10.68	2.07
F3	-2.57	2.82	42	-0.91	0.37	-8.26	3.12
F4	0.62	2.80	42	0.22	0.83	-5.03	6.27
Pz	3.82	4.67	42	0.82	0.42	-5.61	13.26
P3	5.87	3.44	42	1.71	0.10	-1.07	12.81
P4	16.81	8.05	42	2.09	0.04	0.56	33.06
Estimates of Covariance Parameters							
	Estimate	Standard Error			Significance	95% CI: Lower	95% CI: Upper
Fz	3.36	0.73			0.00	2.19	5.15
F3	2.67	0.58			0.01	1.74	4.10
F4	2.64	0.58			0.01	1.72	4.05
Pz	7.35	1.60			0.01	4.80	11.28
P3	3.98	0.87			0.01	2.59	6.10
P4	21.83	4.76			0.01	14.23	33.48

Chapter 3: Appendix II

Easy Abstract

Social anxiety is among the most common mental health issues in the world. People who suffer from social anxiety might try to avoid social situations entirely. In this case they might miss out on important experiences. In other cases, they may try to endure these situations and experience negative emotions and social issues as a result. As such, it is important to understand how anxiety works. This will help us treat it more effectively.

Our study looks at the relationship between social anxiety and brain structure. Specifically, we tested whether unusual patterns in brain connections could be used to diagnose social anxiety on an individual level.

In order to test this theory, we took MRI brains scans of a sample of 40 people. 20 of the people in our study had been diagnosed with social anxiety before, and 20 were healthy controls. To analyse the data, we split the entire brain into 116 regions. We then used this information to see if there were significant differences between the social anxiety patients and control subjects. We saw a classification success rate of 82.5%.

This high success rate suggests that the method we used to analyse the brain can serve as a reliable method for diagnosing social anxiety. But this tool should be used alongside regular psychiatry. This research marks a large stride in improving our understanding of this common disorder. It may even help us understand how it might be treated. Understanding how the physical structure of the brain affects social anxiety is useful. It contributes valuable insights that may pave the way for more effective diagnostic and therapeutic approaches in the future.

Hard Abstract

Amongst the most commonplace psychiatric health disorders in the world is social anxiety disorder (SAD) which is a problem because if a patient has SAD they might choose to either disengage from negative situations entirely or endure them – thus experiencing negative emotions and significant functional impairment. Many mental health disorders have a known relationship to brain functional connectivity (BFC) though the exact nature of the relationship between SAD and BFC has largely received little attention from researchers in the past. These researchers have found that SAD is associated with abnormalities in BFC so whether these abnormalities in BFC can be used to potentially diagnose SAD on an individual basis was explored. Resting-state functional magnetic resonance imaging was used to scan 40 patients' brains – 20 of whom had SAD and 20 of whom

were healthy controls. Automatic Anatomical Labelling (AAL) was used to divide the entirety of the brain into 116 separate regions and the BFC correlation between each pair of regions was calculated by computing Person's correlation coefficient, used in multivariate pattern analysis (MVPA) to classify SAD patients from control patients. The MVPA classifier was designed using a linear support vector machine (SVM) which had a success rate of 82.5% with a sensitivity of 85.0% and specificity of 80.0% using a leave-one-out cross-validation methodology. Connections that identified SAD were broadly located within the default mode network, the visual network, the sensory-motor network, and the affective network, with the right orbitofrontal region exhibiting the highest weight in classification. This study conformed previous work conducted by other researchers, found evidence that BFC is potentially a valid complementary tool for diagnosing SAD in patients, and described some novel pathophysiological mechanisms of SAD.

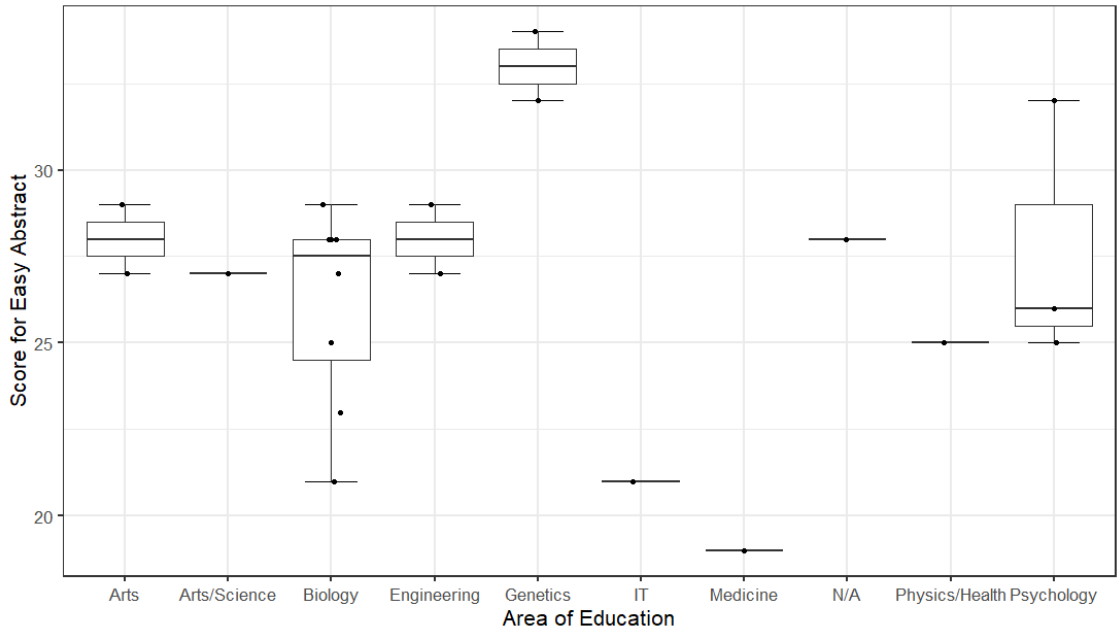
Chapter 3: Appendix III

Key Elements	Prompt	Yes	Prompted	No
This paper examined social anxiety	What topic was this paper investigating, in 1-3 words?			
Social anxiety is a very common disorder	How did the abstract describe social anxiety?			
The researchers wanted to determine if brain structure could be used to diagnose anxiety	What were the researchers trying to find out in this study?			
The researchers used MRI to scan the brain of patients	What technology did the researchers use in this study?			
The sample size was 40 patients	How many patients did the researchers examine?			
20/half of the patients had anxiety, and 20/half were in the control group	Were all the patients in this study the same?			
The researchers divided the brain up into 116 regions	How many regions of the brain did the researchers examine?			
The researchers calculated the functional connectivity between brain regions	What did the researchers calculate based on the brain scans?			
They used differences in functional connectivity to classify patients	How did the researchers use the information they calculated?			
They had a success rate of 82.5% in classifying the patients	What was the success rate they had in diagnosing anxiety?			
The key finding of this study was that functional connectivity can be used as a diagnostic tool	What was the key finding of this study?			
EASY: The paper is a step towards understanding social anxiety and how it can be treated	What broader purpose does this paper serve?			
HARD: The study helps to confirm previous work	What broader purpose does this paper serve?			

- On a scale from 1-5 (with 5 being the easiest), how easy was the abstract to understand?
- On a scale from 1-5 (with 5 being the most confident), how confident are you that you understood?
- On a scale from 1-5 (with 5 being the most), how much did you enjoy the abstract?
- On a scale from 1-5 (with 5 being the hardest), how hard did you need to work mentally?

Chapter 3: Appendix IV

In testing the impact of area of study and level of study, we found little effect on recall scores as a result of these demographic factors. A possible exception was the impact of area of education on the recall scores for the easy abstract, where we found a p-value of 0.05 (one-way ANOVA, $F_{9, 12} = 2.73$, $\eta^2 = 0.67$). In this case, our subjects who studied genetics gained a noticeably higher score than subjects who specialised in other areas (see Supplementary Figure 1). However, this trend cannot be relied upon due to the relatively small sample size and high p-value. No similar trend was observed in the results for the hard abstract (one-way ANOVA, $F_{9, 12} = 1.82$, $p = 0.17$, $\eta^2 = 0.58$).



Supplementary Figure 1. *The distribution of scores (y-axis) for the easy abstract across different areas of study (x-axis). From left to right: Arts, Arts/Science, Biology, Engineering, Genetics, information technology (IT), Medicine, no area of study (N/A), Physics/Health, and Psychology.*

Chapter 4: Supplementary File A – Effect of Year

We tested the effect of the year of publication on the prevalence of our writing features in order to ensure that the year did not significantly impact our results. We ran several two-way ANOVAs to test for a significant interaction item between citations and year (e.g. the 'Citation x Year' term). We compared the effect of publication year and citation frequency against our writing features of interest (see Supplementary Table 1).

With our ANOVA tests, we confirmed a significant relationship between the writing features and their citation frequency. We found that there was no effect of year on the outcome of the analysis of writing features. For the most part, we found no evidence of an interaction between citation frequency and year of publication.

Variables	**Breadth**						**Language**	**Visuals**	
	Title Length	Broad Title	Broad First Line of Abstract	Broad Last Line of Abstract	Broad First Paragraph	Broad Final Paragraph	Motivational Language	Conceptual Images	Interpretive Figure Legends
Citations	0.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Year	0.51	0.67	0.77	0.89	0.61	0.08	0.62	0.17	0.10
Citations x Year	0.58	0.82	0.17	0.55	0.87	0.91	0.71	0.11	0.37

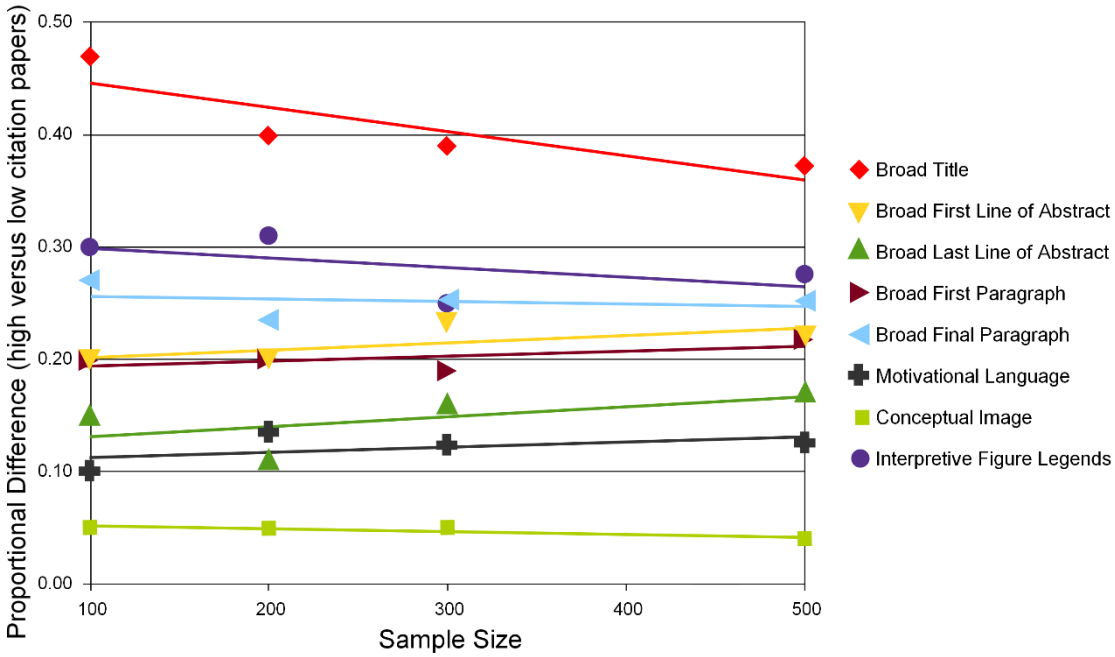
Supplementary Table 1 *This table shows the results of the two-way ANOVA tests. The data is presented as a p-value for each of the writing characteristics examined, against both citations and year as explanatory variables.*

Chapter 4: Supplementary File B – Justification of Sample Size

We tested the effect of sample size in two different ways. In order to determine if an increased sample size would substantially change our results, we randomly sorted the papers within each of the two categories (the highly-cited category and rarely-cited category). We did this by adding an additional column to our spreadsheet, which we then filled with a random number function. We then sorted the data in ascending order based upon this random number.

First, we compared the proportional difference between highly and rarely-cited papers across the first 100 papers, the first 200 papers, the first 300 papers, and the first 500 papers. We then ran a number of Z-tests to see if these proportional differences varied in any significant ways between sample sizes. We found that these proportional differences were insignificant, see Supplementary Figure 1 and Supplementary Table 2.

To confirm this result we used a Chi-Square test to compare papers 1-100, 1-200, 1-300, and 1-500, to see if any of these samples differed significantly from one another. We found no differences between these samples, as shown in Supplementary Table 3.



Supplementary Figure 1 *We calculated the proportional differences in the presence of our writing features of interest between high and low-citation papers over four difference sample sizes. Proportion is displayed on the y-axis and sample-size on the x-axis. These differences were generally small, indicating that increasing the sample size did not significantly impact the results.*

	Breadth					Language	Visuals	
	Broad Title	Broad First Line of Abstract	Broad Last Line of Abstract	Broad First Paragraph	Broad Final Paragraph	Motivational Language	Conceptual Images	Interpretive Figure Legends
High Citations -Total								
100 papers	65	86	41	92	53	36	19	5
200 papers	121	169	81	180	111	77	40	10
300 papers	183	258	121	277	152	124	61	15
500 papers	293	431	208	463	259	204	95	22
Low Citations -Total								
100 papers	18	71	21	65	23	16	10	0
200 papers	41	147	41	133	49	37	15	0
300 papers	66	210	64	201	77	54	21	0
500 papers	107	346	99	337	121	93	40	2
Proportional Difference – High and Low Citations								
100 papers	0.47	0.15	0.20	0.27	0.30	0.20	0.10	0.05
200 papers	0.40	0.11	0.20	0.24	0.31	0.20	0.14	0.05
300 papers	0.39	0.16	0.19	0.25	0.25	0.23	0.12	0.05
500 papers	0.37	0.17	0.22	0.25	0.28	0.22	0.13	0.04
Z Test for Significance (displayed as p-values)								
100 vs 200	0.25	0.99	1.00	0.57	0.86	1.00	0.32	1.00
200 vs 300	0.83	0.11	0.27	0.80	0.14	0.42	0.65	1.00
300 vs 500	0.58	0.71	0.31	1.00	0.35	0.74	0.68	0.66

Supplementary Table 2 *We used a z-test to compare how the proportional differences between low and high-citation papers changed with an increasing sample size. We found that there were no significant differences between these proportions which emerged due to the increasing sample size.*

	Breadth					Language	Visuals	
	Broad Title	Broad First Line of Abstract	Broad Last Line of Abstract	Broad First Paragraph	Broad Final Paragraph	Motivational Language	Conceptual Images	Interpretive Figure Legends
High Citations								
1-100 vs 1-200	0.45	0.73	0.93	0.57	0.68	0.67	0.84	0.45
1-200 vs 1-300	0.91	0.64	0.97	0.36	0.29	0.53	0.93	1.00
1-300 vs 1-500	0.50	0.94	0.72	0.89	0.76	0.88	0.64	0.70
Low Citations								
1-100 vs 1-200	0.61	0.65	0.92	0.80	0.77	0.59	0.43	n/a*
1-200 vs 1-300	0.69	0.40	0.82	0.91	0.77	0.89	0.53	n/a*
1-300 vs 1-500	0.84	0.81	0.60	0.91	0.64	0.83	0.39	n/a*

Supplementary Table 3 *This table provides evidence that increasing the sample size from 100, to 200, to 300 papers does not significantly alter the proportion of papers that display a certain characteristic. Results are displayed as a p-value determined by a Chi-Square test.*

** Could not be calculated as samples had a '0' for Interpretive Figure Legends.*

Chapter 4: Supplementary File C – Analysis of Confirmation Bias

To test the potential impacts of confirmation bias, we randomly selected 50 low-citation and 50 high-citation papers from our sample (n = 100). We then shuffled these papers to distribute the high and low citation papers. Fifty of the randomly-sorted papers were given to one PhD researcher, and the other 50 to another. These researchers were blinded as to the citation frequency of the papers they received. We compared these results to our initial analysis (see Supplementary Table 4), using Fisher's Exact test to determine significance.

There were some differences in the researchers' findings. In contrast to the additional researchers, the original researcher failed to detect significant differences between high and low-citation papers in the areas of the first line of the abstract and the last line of the abstract. However, when examining all 1000 papers, the initial researcher had previously found differences in these areas. Because the additional researchers detected this trend in the smaller (n =100) sample size – where the initial researcher did not – this suggests that the initial researcher may have been conservative in determining "broadness", therefore under-estimating the significance of this difference, further supporting the overall conclusions of the paper.

The differences we found between high and low-citation papers in the random sample of 100 papers was not the same as the differences we found in our overall sample of 1000 papers. But both the initial and additional researchers agreed that there is a significant difference between high and low-citation papers in the areas of: broad titles, broad first paragraphs, broad final paragraphs, and motivational language. Neither the initial nor additional researchers found a significant difference between high and low-citation papers in the areas of conceptual images or interpretive figure legends.

Researcher	Citations	Breadth					Language	Visuals	
		Broad Title	Broad First Line of Abstract	Broad Last Line of Abstract	Broad First Paragraph	Broad Final Paragraph	Motivational Language	Conceptual Images	Interpretive Figure Legends
Initial	Low	13	40	13	31	11	9	4	0
Initial	High	33	42	20	50	31	19	9	3
Initial	*P-values*	*0.01**	*0.4*	*0.1*	*0.01**	*0.01**	*0.02**	*0.12*	*0.12*
Additional	Low	14	26	19	40	24	3	3	5
Additional	High	35	43	37	48	40	11	9	9
Additional	*P-values*	*0.01**	*0.01**	*0.01**	*0.01**	*0.01**	*0.02**	*0.06*	*0.19*

Supplementary Table 4 *We compare the results of the initial and additional researchers, in terms of how they judge the differences between the prevalence of specific writing features in low versus high-citation papers. Data is presented as a total sum of samples which show a specific feature. The rows labelled as 'P-values' refer to the comparison between the two rows above them. Namely, high versus low-citation papers; with a p-value provided for the results from the initial researcher, and another p-value for the results from the additional researchers.*

Chapter 4: Supplementary File D – Motivational Language

Taking cues from Millar, Batalo, and Budgell's previous work (Millar, Batalo, & Budgell 2022), we examined the abstracts of the papers for motivational language. The following is a list of the words we classified as motivational for the purposes of our study.

Abrupt	Key
Acute	Large/st (e.g. consequences)
Aggressive	Major
Alarming	Massive
Astonishing	Millions (e.g. of people)
Attractive	Most (e.g. pressing, isolated)
Backbone	Most important
Bad	Must
Big/gest	Necessary
Boom	Necessity
Brink of collapse	Need
Broad	New
Careful	Notoriously
Central	Novel
Clear	Numerous
Complex	One of the largest
Comprehensive	One of the last
Considerable	Overlooked
Core	Overwhelming/ly
Critical/ly	Persistent
Crucial	Perverse
Decades-long	Pitted
Decisive	Pivotal
Detailed	Plea
Distinctive	Poorly
Dramatic/ally	Powerful
Drastic	Primary
Enamoured	Profound/ly
Enormous	Pronounced
Escalated	Puzzling
Especially	Radical/ly
Essential	Rapid/ly
Ever-greater	Rare
Exceptional	Remarkable/Remarkably
Exploitation	Rich/est
Explosion (e.g. of research)	Rigorous/ly
Extensive	Ripe
Extraordinary	Robust
Extreme/ly	Serious
Fastest (e.g. growing)	Severe/ly
First	Sharp/ly
Foundation	Significant/ly (e.g. damage, impact)
Frightening	Sobering
Fundamental/ly	Sparse
Generalisable	Special
Global	Striking

Great/ly/est (e.g. diversity, importance)	Strong/ly
Heavy/Heavily	Substantial
High/ly (e.g. level of threat)	Surging
Highlights	Surprising
Hotspot	Survival
Ideal	Systematic
Immense	Timely
Imperative	Unique
Important	Unprecedented
In the world	Urgent/cy/ly
Indispensable	Valuable
Inefficient	Vast
Inevitably	Very
Inherently	Virgin (e.g. opportunity)
Innovative	Vital/ly
Insidious	Widely
Integral	Widespread
Invisible	Worldwide
Irreversible	Worst
Keen	

Chapter 4: Supplementary File E – Results of Statistical Analysis

	Breadth						Language	Visuals	
	Broad Title	Title Length (Average)	Broad First Line of Abstract	Broad Last Line of Abstract	Broad First Paragraph	Broad Final Paragraph	Motivational Language	Conceptual Images	Interpretive Figure Legends
High Citations	63.6% (n = 318)	14.186	86.2% (n = 431)	41.6% (n = 208)	92.6% (n = 463)	51.8% (n = 259)	40.8% (n = 204)	19% (n = 95)	4.4% (n = 22)
Low Citations	23.2% (n = 116)	14.898	69.2% (n = 346)	19.8% (n = 99)	67.4% (n = 337)	24.2% (n = 121)	18.6% (n = 93)	6.4% (n = 32)	0.4% (n = 2)
Z-Test	12.001	n/a	6.457	7.473	9.961	8.991	7,682	5.983	4.132
P-Value	<0.0001	n/a	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Supplementary Table 5 *This table shows how researchers can include different writing features in their papers to attract readers' attention. Each category reflects the percentage (%) of papers which displayed the writing features of interest. The sample size was 500 for both highly and rarely-cited papers (excepting 'Title Length' which is displayed as an average). The data is the same as is presented in Figure 2, but displays the Z-test and p-value results.*

Chapter 5: Appendix I – How valued are science communicators?

To test whether citations and author H-index were truly correlated to teachers coordinating statistics and theory courses, we compared the coordinators teaching science communication, basic statistics for biologists, and ecological theory courses. Table 3 – as discussed in this paper – shows the average metrics from across all institutions. To see if these patterns held within institutions, we ranked these coordinators within their institutions with a number from 1-3, with 1 indicating the highest h-index and 3 the lowest. For institutions where multiple subjects were sampled, or when a single subject was taught by multiple coordinators; we ranked the subjects by averaging the h-index. We then averaged these rankings for all institutions to see – on average – which subjects had the highest-ranking coordinators (see Table 4). To further visualise the data, we plotted a scatterplot comparing the citation frequency of these coordinators against their H-index (see Figure 5).

This additional analysis confirmed our previous findings. We found that ecological theory courses typically had the highest-ranked professors, followed by biological statistics, with science communication courses having the lowest-ranked professors on average.

Table 4 *A table showing the relative ranking of coordinators' h-index, publication number, and citation number within institutions and between subjects. Smaller numbers indicate a higher relative ranking. Cells marked with a '-' indicate that the institution does not offer a subject in this area.*

Institution	**Sci Comm**	**Statistics**	**Theory**
Australian National University	1	3	2
The University of Western Australia	2	3	1
The University of Melbourne	3	2	1
The University of Queensland	-	1	2
Monash	3	1	2
The University of Adelaide	3	1	2
The University of Sydney	3	2	1
The University of Tasmania	3	2	1
Cambridge University	-	1	2
Brown University	-	1	2
Harvard University	3	2	1
Princeton University	2	-	1
Yale University	2	3	1
Average:	**2.50**	**1.83**	**1.46**

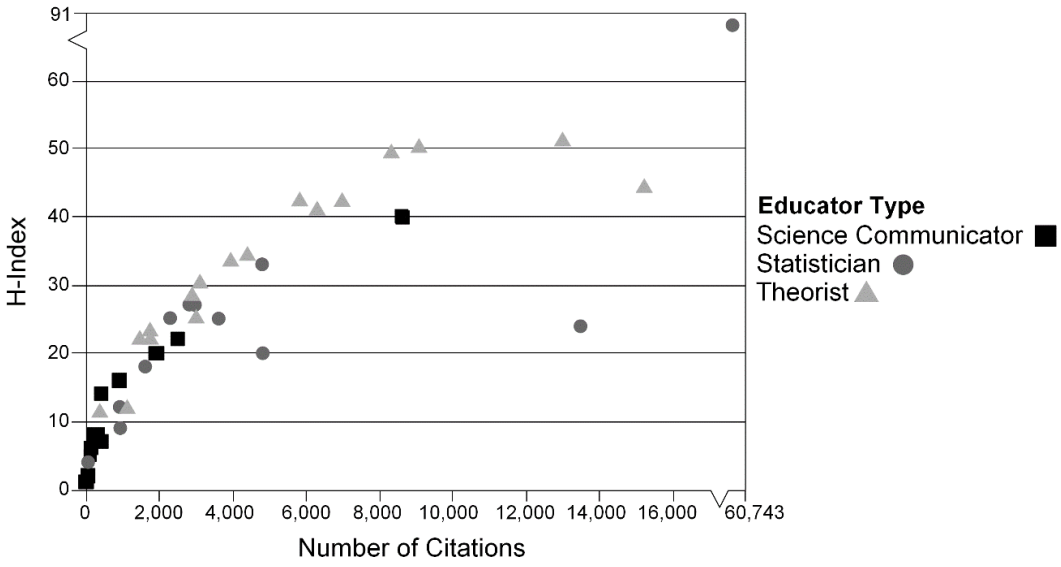
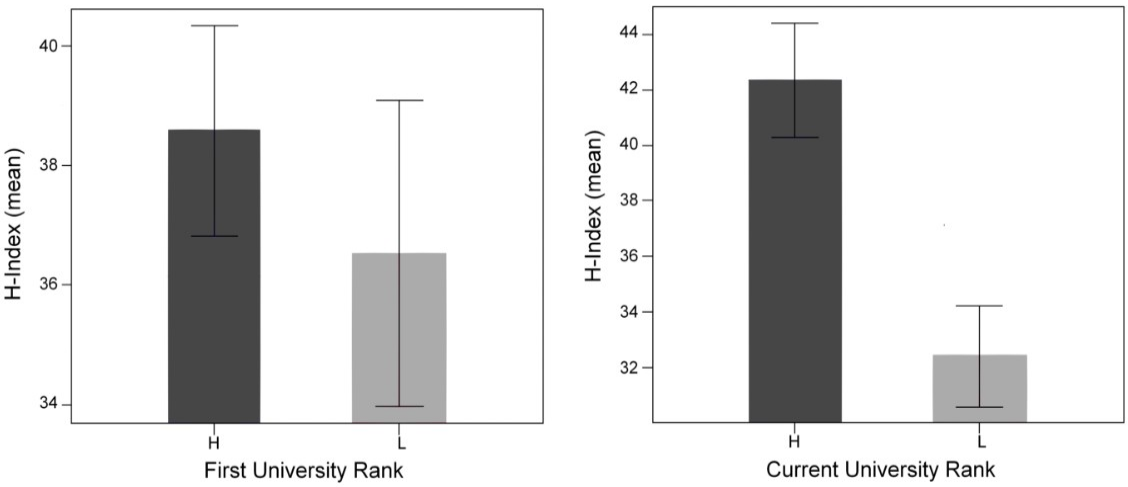


Figure 5 *A graph showing the relationship between the total number of citations obtained by a course coordinator and their H-index. Black squares represent course coordinators for science communication courses (biology communicators), dark grey circles represent coordinators for statistics courses (biological statisticians), and light grey triangles represent coordinators for theory courses (biological theorists). Figure generated in LibreOffice Calc and edited in Fire Alpaca.*

Chapter 6: Appendix I

In conducting the research for this chapter, we discovered some expected results. These expected findings indicate that our sampling method and statistical analysis were appropriate for this study.

We found that higher prestige universities tended to attract higher-ranked academics, as determined by H-index. This was true regardless of whether the university rank variable was categorical or continuous. More specifically, there is no clear link between the H-index an academic obtains and their *starting* institution rank, but we detected a positive relationship between the H-index of an academic and their rank of their *current* institution. This suggests that high-ranking universities have the potential to elevate the academic performance of their researchers, through such things as networking opportunities and access to resources (see Supplementary Figure 1).



Supplementary Figure 1 *The differences in H-index between researchers at high ranking (dark grey) versus low-ranking universities (light grey). The left-hand graph shows that there is no significant relationship between the institution the researchers start at and the H-index they eventually obtain (one-way ANOVA, p = 0.496, F = 0.47). However, the right-hand graph does show a significant positive relationship between higher H-indices and the rank of the institution the researcher currently works at (one-way ANOVA, p = <0.01, F = 12.54). This suggests that high-ranking institutions are better able to support their researchers and enable them to achieve higher H-indices.*

The highly-ranked universities also tended to produce higher prestige papers, as determined by FWCI (see Table 1 & 2), average citation impact (see Table 3), and journal impact factor (see Supplementary Table 1). Likewise, we found that earlier publication dates resulted in higher H-indices and FWCIs for academics (see Table 1), which is to be expected as researchers who have been publishing longer will have a wider range of papers and a more well-established career.

Supplementary Table 1 *The differences between high and low-ranking institutions, in regard to the impact factor of journals which their researchers publish in. Data is presented as a percentage of total papers published. The p-values and F-statistics provided were generated via a one-way ANOVA.*

University Rank	% Q1 Papers	% Q2 Papers	% Q3 Papers	% Q4 Papers
High	61.18%	26.07%	8.88%	3.87%
Low	50.18%	32.01%	12.54%	5.27%
P-value	*<0.01**	*<0.01**	*<0.01**	*0.06**
F-statistic	*43.66*	*33.40*	*12.65*	*7.93*

Chapter 6: Appendix II

Year	Paper Type	P-value	F-value	Standard Deviation	Means
ALL	% OA	<0.001**	22.27	H: 6.43, L: 7.99	H: 52.90, L: 45.25
	% Both	<0.001**	19.86	H: 4.84, L: 4.89	H: 22.88, L: 18.03
	% Other Open	0.089	2.96	H: 3.53, L: 5.49	H: 16.25, L: 14.48
	% Closed	<0.001**	22.55	H: 6.43, L: 7.99	H: 47.05, L: 54.75
	% Pub Open	0.030*	5.02	H: 1.52, L: 2.57	H: 13.83, L: 12.75
2000	% Both	<0.001**	66.99	H: 1.37, L: 1.16	H: 4.65, L: 2.33
	% Other Open	<0.001**	28.86	H: 3.14, L: 2.58	H: 9.05, L: 5.60
	% Closed	<0.001**	52.15	H: 6.17, L: 5.97	H: 71.93, L: 81.73
	% Pub Open	<0.001**	15.36	H: 4.32, L: 4.06	H: 14.03, L: 10.35
2001	% Both	<0.001**	55.24	H: 1.65, L: 1.27	H: 4.80, L: 2.25
	% Other Open	<0.001**	17.30	H: 3.18, L: 2.77	H: 9.30, L: 6.53
	% Closed	<0.001**	41.12	H: 6.28, L: 5.55	H: 72.20, L: 80.70
	% Pub Open	<0.001**	13.05	H: 3.63, L: 4.44	H: 13.70, L: 10.43
2002	% Both	<0.001**	70.75	H: 1.71, L: 1.41	H: 5.70, L: 2.75
	% Other Open	<0.001**	15.90	H: 3.30, L: 2.53	H: 9.83, L: 7.20
	% Closed	<0.001**	64.59	H: 5.42, L: 4.97	H: 69.85, L: 79.20
	% Pub Open	<0.001**	26.57	H: 2.74, L: 3.69	H: 14.63, L: 10.88
2003	% Both	<0.001**	65.56	H: 1.66, L: 1.51	H: 5.95, L: 3.08
	% Other Open	<0.001**	22.78	H: 3.45, L: 2.63	H: 10.80, L: 7.53
	% Closed	<0.001**	55.87	H: 5.17, L: 6.07	H: 69.28, L: 78.70
	% Pub Open	<0.001**	16.61	H: 2.76, L: 4.27	H: 13.98, L: 10.70
2004	% Both	<0.001**	78.02	H: 1.78, L: 1.44	H: 6.43, L: 3.23
	% Other Open	<0.001**	23.60	H: 3.71, L: 2.82	H: 11.43, L: 7.85
	% Closed	<0.001**	62.27	H: 5.69, L: 5.79	H: 67.85, L: 77.98
	% Pub Open	<0.001**	14.86	H: 3.10, L: 4.54	H: 14.30, L: 10.95
2005	% Both	<0.001**	80.91	H: 1.90, L: 1.51	H: 7.15, L: 3.70
	% Other Open	<0.001**	21.55	H: 3.73, L: 3.34	H: 12.40, L: 8.73
	% Closed	<0.001**	59.89	H: 5.57, L: 6.06	H: 66.45, L: 76.53
	% Pub Open	<0.001**	14.29	H: 2.61, L: 4.19	H: 14.00, L: 11.05
2006	% Both	<0.001**	74.12	H: 2.04, L: 1.71	H: 7.23, L: 3.60
	% Other Open	<0.001**	13.00	H: 3.76, L: 3.43	H: 12.78, L: 9.88
	% Closed	<0.001**	57.93	H: 5.47, L: 5.10	H: 66.60, L: 75.60
	% Pub Open	<0.001**	14.09	H: 2.50, L: 3.34	H: 13.40, L: 10.93
2007	% Both	<0.001**	58.38	H: 2.62, L: 1.95	H: 8.73, L: 4.78

	% Other Open	<0.001**	16.56	H: 4.19, L: 3.88	H: 14.55, L: 10.88
	% Closed	<0.001**	47.17	H: 6.29, L: 6.08	H: 64.30, L: 73.80
	% Pub Open	0.012*	6.63	H: 3.09, L: 3.42	H: 12.43, L: 10.55
2008	% Both	<0.001**	55.72	H: 3.28, L: 2.58	H: 11.28, L: 6.35
	% Other Open	0.002*	10.44	H: 5.17, L: 5.21	H: 17.05, L: 13.30
	% Closed	<0.001**	39.83	H: 7.26, L: 7.33	H: 60.05, L: 70.35
	% Pub Open	0.008*	7.47	H: 1.99, L: 3.19	H: 11.63, L: 10.00
2009	% Both	<0.001**	46.19	H: 3.94, L: 3.23	H: 12.63, L: 7.15
	% Other Open	0.002*	10.42	H: 6.17, L: 4.84	H: 17.45, L: 13.45
	% Closed	<0.001**	37.87	H: 8.71, L: 6.96	H: 58.55, L: 69.40
	% Pub Open	0.011*	6.77	H: 2.12, L: 2.58	H: 11.38, L: 10.00
2010	% Both	<0.001**	42.58	H: 3.91, L: 3.66	H: 13.93, L: 8.40
	% Other Open	0.003*	9.11	H: 6.24, L: 4.60	H: 17.60, L: 13.90
	% Closed	<0.001**	34.23	H: 9.06, L: 7.19	H: 56.30, L: 67.00
	% Pub Open	0.007*	7.68	H: 1.89, L: 2.78	H: 12.18, L: 10.70
2011	% Both	<0.001**	55.67	H: 4.15, L: 3.84	H: 16.78, L: 10.10
	% Other Open	0.002*	10.58	H: 5.73, L: 3.85	H: 16.48, L: 12.93
	% Closed	<0.001**	20.54	H: 8.43, L: 10.81	H: 55.20, L: 65.03
	% Pub Open	0.47	0.54	H: 1.84, L: 3.43	H: 11.55, L: 11.10
2012	% Both	<0.001**	52.51	H: 4.57, L: 4.35	H: 19.65, L: 12.43
	% Other Open	0.004*	8.60	H: 5.27, L: 3.85	H: 15.60, L: 12.58
	% Closed	<0.001**	22.36	H: 8.04, L: 10.81	H: 53.28, L: 63.35
	% Pub Open	0.909	0.01	H: 2.05, L: 7.99	H: 11.48, L: 11.63
2013	% Both	<0.001**	43.78	H: 4.72, L: 4.67	H: 20.58, L: 13.63
	% Other Open	0.009*	7.13	H: 4.81, L: 4.30	H: 15.95, L: 13.23
	% Closed	<0.001**	46.58	H: 7.52, L: 7.12	H: 51.85, L: 63.03
	% Pub Open	<0.001**	12.03	H: 1.79, L: 2.07	H: 11.63, L: 10.13
2014	% Both	<0.001**	30.18	H: 5.21, L: 5.37	H: 22.95, L: 16.45
	% Other Open	0.672	0.18	H: 4.34, L: 7.37	H: 15.93, L: 15.35
	% Closed	<0.001**	20.38	H: 7.62, L: 9.24	H: 49.13, L: 57.68
	% Pub Open	0.002*	10.74	H: 1.38, L: 2.49	H: 12.00, L: 10.53
2015	% Both	<0.001**	29.21	H: 5.86, L: 5.38	H: 25.63, L: 18.83
	% Other Open	0.835	0.04	H: 4.13, L: 8.11	H: 15.63, L: 15.33
	% Closed	<0.001**	16.56	H: 8.24, L: 10.18	H: 45.93, L: 54.35
	% Pub Open	0.010*	6.96	H: 1.60, L: 2.75	H: 12.83, L: 11.50
2016	% Both	<0.001**	27.32	H: 5.61, L: 5.62	H: 27.75, L: 20.58

	% Other Open	0.945	0.01	H: 4.98, L: 10.39	H: 17.30, L: 17.43
	% Closed	0.003*	9.60	H: 9.61, L: 11.26	H: 41.80, L: 49.05
	% Pub Open	0.784	0.08	H: 2.36, L: 3.94	H: 13.15, L: 12.95
2017	% Both	<0.001**	21.39	H: 6.43, L: 6.67	H: 29.28, L: 22.50
	% Other Open	0.717	0.13	H: 5.13, L: 11.54	H: 17.68, L: 18.40
	% Closed	0.011*	6.76	H: 9.28, L: 12.28	H: 39.85, L: 46.18
	% Pub Open	0.741	0.11	H: 2.58, L: 4.56	H: 13.20, L: 12.93
2018	% Both	<0.001**	15.29	H: 6.53, L: 6.90	H: 30.78, L: 24.90
	% Other Open	0.692	0.16	H: 5.08, L: 10.81	H: 17.73, L: 18.48
	% Closed	0.027*	5.09	H: 8.84, L: 12.56	H: 37.95, L: 43.43
	% Pub Open	0.642	0.22	H: 2.76, L: 3.85	H: 13.55, L: 13.20
2019	% Both	<0.001**	12.96	H: 6.05, L: 6.84	H: 30.40, L: 25.20
	% Other Open	0.600	0.28	H: 5.08, L: 11.23	H: 18.03, L: 19.05
	% Closed	0.053	3.87	H: 8.34, L: 12.60	H: 37.23, L: 41.93
	% Pub Open	0.538	0.38	H: 3.04, L: 4.42	H: 14.35, L: 13.83
2020	% Both	0.002*	9.92	H: 6.70, L: 7.69	H: 32.80, L: 27.73
	% Other Open	0.936	0.01	H: 3.85, L: 8.95	H: 19.23, L: 19.35
	% Closed	0.022*	5.43	H: 7.89, L: 11.21	H: 33.88, L: 38.93
	% Pub Open	0.906	0.01	H: 2.66, L: 4.62	H: 14.10, L: 14.00
2021	% Both	0.048*	4.03	H: 6.91, L: 8.99	H: 33.90, L: 30.30
	% Other Open	0.314	1.03	H: 3.52, L: 6.79	H: 19.60, L: 18.38
	% Closed	0.065	3.51	H: 7.46, L: 11.36	H: 32.30, L: 36.33
	% Pub Open	0.290	1.13	H: 2.57, L: 3.99	H: 14.20, L: 15.00
2022	% Both	0.135	2.28	H: 6.98, L: 9.54	H: 34.10, L: 31.28
	% Other Open	0.022*	5.43	H: 3.42, L: 4.98	H: 17.48, L: 15.25
	% Closed	0.032*	4.80	H: 6.55, L: 10.21	H: 33.48, L: 37.68
	% Pub Open	0.241	1.39	H: 2.33, L: 3.91	H: 14.95, L: 15.80
2023	% Both	0.239	1.41	H: 6.82, L: 9.86	H: 30.03, L: 27.78
	% Other Open	<0.001**	19.39	H: 3.32, L: 3.13	H: 13.95, L: 10.78
	% Closed	0.007*	7.68	H: 6.75, L: 9.48	H: 34.58, L: 39.68
	% Pub Open	0.722	0.13	H: 3.65, L: 4.46	H: 21.45, L: 21.78

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