A survey on the attitudes towards and perception of reproducibility and replicability in sports and exercise science

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Abstract:

There are formal calls for increased reproducibility and replicability in sports and exercise science, yet there is minimal information on the overall knowledge of these concepts at a field-wide level. Therefore, we conducted a survey on the attitudes and perceptions of sports and exercise science researchers towards reproducibility and replicability. Descriptive statistics (e.g., proportion of responses), and thematic analysis, were utilized to characterize the responses. Of the 511 respondents, 42% (n = 217) believe there is a significant crisis of reproducibility or replicability in sports and exercise science while 36% (n = 182) believe there is a slight crisis. 3% (n = 15) of respondents believe there is no crisis while 19% (n = 95) did not know. Four themes were generated in the thematic analysis: the research and publishing culture, educational barriers to research integrity, research responsibility to ensure reproducibility and replicability, and current practices facilitating reproducibility and replicability. Researchers believe that engaging in open science can be detrimental to career opportunities due to lack of incentives. They also feel journals are a barrier to reproducible and replicable research due to high publication charges and a focus on novelty. Statistical expertise was identified as a key factor for improving reproducibility and replicability in the future, particularly, a better understanding of study design and different statistical techniques. Statistical education should be prioritised for early career researchers which could positively affect publication and peer review. Researchers must accept responsibility for reproducibility and replicability with thorough project design, appropriate planning of analyses, and transparent reporting practices.

Keywords: replication, reproducibility, sports science, statistics, education, transparency

1 Introduction

The recent concept of replication has gained attention in psychology due to a failure to replicate studies (Klein *et al.*, 2014; Open Science Collaboration, 2015). However, it has also expanded to other fields such as social science (Camerer *et al.*, 2018), economics (Camerer *et al.*, 2016), and cancer biology (Errington *et al.*, 2021), whereby similar large replication projects suggested a crisis of confidence in research findings (Pashler and Wagenmakers, 2012). This "replication crisis" led to discussions around the replicability, reproducibility (retesting a claim using the same data and comparable analyses as opposed to replication which uses new data; Nosek & Errington, 2020), and transparency of research practices which helped inspire the open science movement (Munafò *et al.*, 2017).

The response to the "replication crisis" was met with mixed reaction. Those in favour of replication studies believe they can increase (or decrease) confidence in research findings, update boundaries on findings i.e., the external validity (Nosek and Errington, 2020), identify type I errors, and control for sampling error (Schmidt, 2009). However, there are arguments that concerns regarding replication are overblown, as replicability is not an ideal for all disciplines in science and cannot be universally applied (Guttinger, 2020). Others believe it is a waste of valuable resources and misguided to undertake large replication efforts (Stroebe and Strack, 2014; Prieto, 2017).

Due to the contrasting views on the value of replication and reproducibility, a *Nature* survey explored the opinions of researchers in different fields (Baker and Penny, 2016). Of 1576 researchers, 52% believed there was a significant reproducibility crisis and 38% believed there was a slight crisis in science. A similar survey of psychologists was conducted to understand the community's opinion on the importance of replication (Buttliere and Wicherts, 2018); results showed the community viewed replications as an essential aspect of the research process to determine what effects are "real". Although replication is one of the "most obvious ingredients of science" (Schmidt, 2009, p. 91), it is not the norm across all scientific disciplines causing a period of unrest amongst those who advocate for it.

The issues of replication have yet to be examined in sports and exercise science, despite several publications identifying methodological and statistical concerns, and advocating for increased replication studies within the discipline (Heneghan *et al.*, 2012; Halperin, Pyne and Martin, 2015; Knudson, 2017; Caldwell *et al.*, 2020). Some single study replication attempts were published in the field (e.g., Pitsch and Emrich, 2012; Chalmers et al., 2018; Morin et al., 2019), and there is an ongoing large replication project (Murphy *et al.*, 2023). Additionally, research groups were formed to improve the manner in which we conduct research in the field (e.g., STORK; the Society for Transparency, Openness and Replication in Kinesiology). Yet, as replication has not grasped the attention of sports and exercise science like other fields (e.g., psychology, social science, cancer biology and economics), there is limited field-wide discussion on the concept. Consequently, there is no understanding of the attitudes towards, and perception of, reproducibility and replication in sports and exercise science to date. It is therefore difficult to gauge how accepting sports and exercise science researchers are of reproducibility and replicability at a field-wide level and, if opposed to it, the reasons for reluctance to embrace changes.

Publishers and journals are accused of prioritising novel findings over replication studies for higher impact and to increase their journal metrics (Nosek, Spies and Motyl, 2012; Chambers *et al.*, 2014), which detracts from replication efforts. Replication is also considered to be a less inferior and creative method of research by some (Makel and Plucker, 2014). Other researchers are opposed to replication as they feel it is a personal attack on their work and "a hostile action" (Nosek *et al.*, 2022, p. 20). Thus, it is crucial to understand the barriers to the open science movement, particularly replication for this field, as this movement is affecting all areas of social science. By identifying the barriers to undertaking replication, changes can be implemented to incentivise researchers to adapt their methods and improve research practices. This information is essential to facilitate an increased number of replication studies, build awareness of current practices, and increase collaboration and transparency amongst researchers and statisticians alike (Caldwell *et al.*, 2020; Sainani *et al.*, 2021).

The purpose of this survey is to explore the attitudes and perceptions of researchers towards reproducibility and replicability in the field of sports and exercise science, by adapting the established *Nature* survey (Baker and Penny, 2016). The objectives of this study are to understand the community awareness of the terms reproducibility and

replicability, and the attitudes towards these concepts, and to identify potential barriers to reproducibility and replicability in sports and exercise science.

2 Methods

2.1 Recruitment Strategy

To be included in this study, participants must be active researchers, therefore, the sample was limited to researchers who had published in a sports and exercise science journal in the previous 5 years to the survey distribution (2016 - 2021). As per the preregistration, we aimed to have a final sample size close to 2000. This sample size was based on similar surveys to our topic (Baker and Penny, 2016; Ross-Hellauer, Deppe and Schmidt, 2017; Buttliere and Wicherts, 2018). All participants were informed through the survey website that it was anonymous and voluntary. Participants were informed that the study results and underlying data would be published. Participants provided consent using a digital informed consent form that was completed prior to beginning the survey.

2.2 Participants

There were 511 responses to the survey representing a response rate of 2.7%. For the demographics, 38% were from North America, 37% from Europe, 12% from Australasia, 6% from Asia, 5% from South America, and 2% from Africa. 31% of respondents were aged between 25 and 34 years, 36% from 35 to 44 years, and 18% from 45 to 54 years. Most respondents selected "Associate Professor" as their main job role (27%), followed by "Professor" (21%), "Post-doctoral Fellow" (10%), and "PhD student" (8%).

2.3 Preregistration Deviation

We originally planned to contact 10,000 sports and exercise science researchers via the mailing list of corresponding authors who had published in sports and exercise science journals according to the Web of Science research database (www.webofknowledge.com). However, we deviated from the preregistration due to very low response rates and contacted a total of 23,690 researchers instead. These were sent between May and July 2021 and 18,854 emails were delivered. The undelivered emails (N = 4836) were due to researchers moving institutions, university spam filters

and other unknown reasons. We hypothesize low response rates could be a result of the survey length (mean completion time = 68:21 minutes), time of distribution (summer/university holidays) and no follow up reminder.

2.4 Experimental Design

The survey was adapted from a previously published *Nature* survey which explored scientist's opinions on reproducibility in their field and other fields (Baker and Penny, 2016). Minor adaptations included the addition of questions relating to replication to those already focused on reproducibility. Questions were adapted to be specific to sports and exercise science such as "*In the field of sports and exercise science...*". This survey included 20 short sections and 45 questions with a focus on: familiarity of terminology; perception of the reproducibility/replication crisis; the proportion of published results that are reproducible or replicable; funder and publisher efforts to improve reproducibility and replicability; established procedures for reproducibility and replicability, and the impact of these on the laboratory; barriers to reproducibility and replicability; contributory factors to a failure to reproduce or replicate results; and factors that would improve reproducibility and replicability. The following definitions were provided in the survey: reproducibility is defined as retesting a claim using the same analyses and same data, whereas replication is retesting a claim using the same analyses and new data (Nosek and Errington, 2020).

Both multiple choice answers and free text boxes were used in the survey. We included open text boxes to capture opinions on reproducibility and replication that multiple choice questions potentially missed. Question skip logic was applied so participants did not have to respond to a question where the answer to the previous question made it irrelevant. The survey is available in full online along with the data, R code and supplementary materials (https://doi.org/10.17605/OSF.IO/64R8M). The preregistration is also available online (https://doi.org/10.17605/OSF.IO/EXK6N). Ethical approval was granted by Technological University Dublin (REC-PGRI-202021).

2.5 Quantitative Data Management and Statistical Analysis

The final analysis included survey responses which were fully completed and where digital consent was received. Data was collected via an encrypted, password protected

online survey software, Microsoft Forms (version 16.63.1; Microsoft Office, Mountain View, CA, USA). There were 10 sections with free text data which consisted of brief sentences in response to the open-ended questions. These responses were transferred to a Microsoft Excel spreadsheet (version 16.63.1; Microsoft Office, Mountain View, CA, USA). Descriptive statistics were conducted for the categorical data (e.g., proportion of responses) using R (version 4.2.1) (R Core Team, 2022).

2.6 Thematic Analysis Approach

The research question for this study was addressed using a reflexive thematic analysis approach. This approach involves "*the researcher's reflective and thoughtful engagement with their data and their reflexive and thoughtful engagement with the analytic process*" (Braun and Clarke, 2019, p. 594). As we analysed the data with our aim in mind, the themes are strongly related to the research question and were driven by the researcher's theoretical interest. This is indicative of a deductive analysis; however, inductive analysis was also employed to ensure full interpretation of the data content. Using this type of analysis, responses were open coded to best represent meaning from the participants and a pre-specified coding book was not used.

Semantic coding was initially used to identify themes through engagement with the surface meaning of the data; key words and phrases were highlighted on hardcopies of the transcripts. However, our coding approach was not exclusively semantic as we also interpreted the meaning underpinning responses from the participants in subsequent readings of the data (i.e., latent coding) (Braun and Clarke, 2019). The codes and their corresponding data extracts were then organised into "theme piles" (Braun and Clarke, 2006) and subsequently revised and developed. When codes were organised based on recurring patterns, the sub-themes were formed. These sub-themes were then linked to one another and grouped to form a major theme. Our last step was to collate the data extracts in the table with their corresponding sub-themes and themes. Data extracts were selected in the results for the highest clarity for theme representation, but the dataset is fully available on the OSF project page.

3 Results

3.1 Descriptive Results

Of the 511 respondents, 47% (n = 239) of respondents were “very familiar” and 39% (n = 200) were “fairly familiar” with the term reproducibility, while 30% (n = 152) were “very familiar” and 35% (n = 181) were “fairly familiar” with the term replicability. Over three-quarters (78.1%) of these respondents believe there is a replication and reproducibility crisis in sports and exercise science (Figure 1).

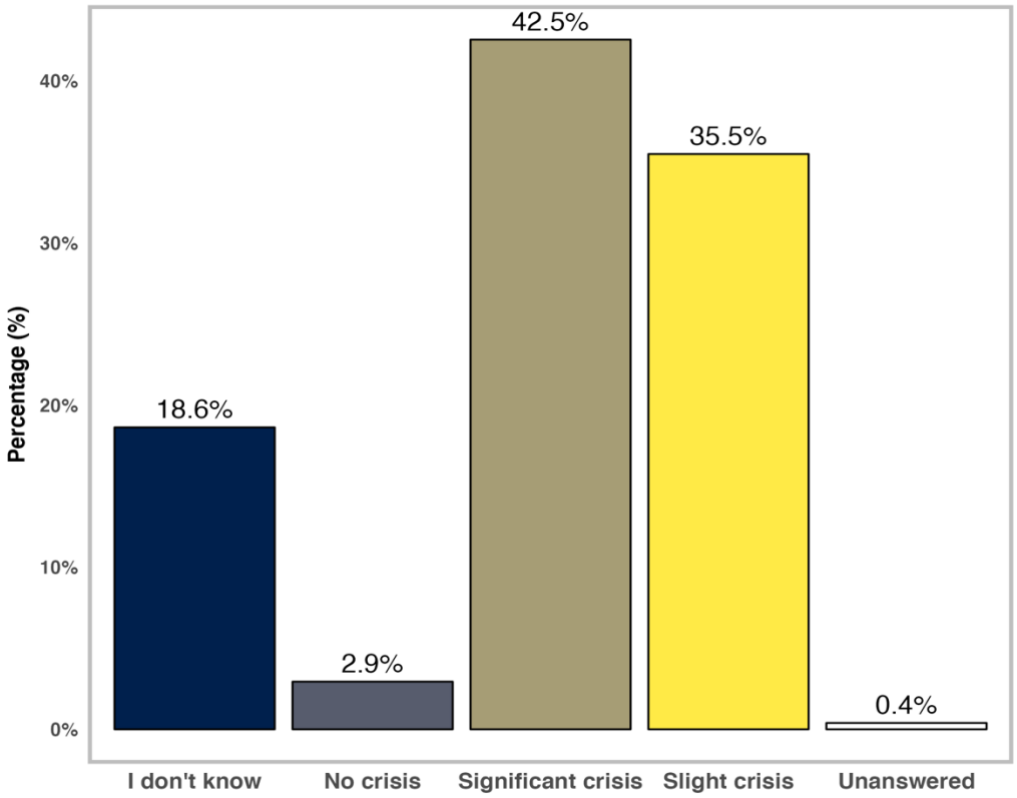

Figure 1. Descriptive results of the response to the survey question about a reproducibility crisis or replication crisis in sports and exercise science.

When responding to a question asking whether they encountered barriers to implementing changes that would improve reproducibility and replicability in the laboratory, 37% of respondents (n = 189) identified barriers, 42% (n = 217) did not, and 20% (n = 102) were unsure. Furthermore, when answering a question on the factors that contribute to a study failing to replicate, respondents believe poor experimental design, insufficient mentoring,

publishing pressure, and selective reporting were among the highest contributing factors (Figure 2).

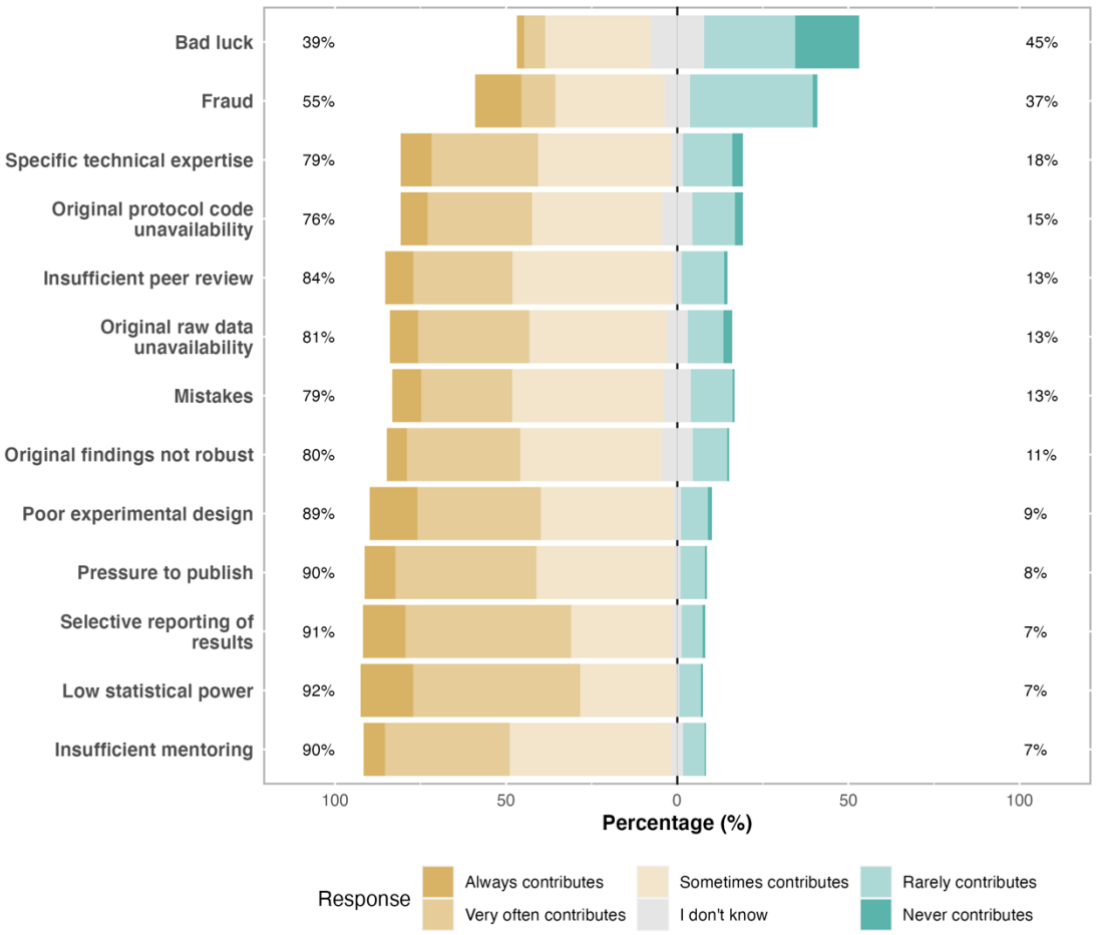

Figure 2. Descriptive results of the response to the survey question on factors contributing to a failure to replicate.

The number to the left of the bar indicates the percentage of participants who responded with "always contributes", "very often contributes", or "sometimes contributes" while the number on the right indicates the percentage of participants who responded with "rarely contributes" or "never contributes". The centre of the bar (grey) indicates those who responded, "I don't know". Statements are ordered according to the total percentage of agreement.

3.2 Thematic Analysis Results

Four key themes were generated from the data after the thematic analysis was applied (Tables 1 - 4). They were the research and publishing culture, educational barriers to research integrity, research responsibility to ensure reproducibility and replicability, and current practices facilitating reproducibility and replicability in the field. A summary of the results is presented below, and the tables include selected quotes and information directly from the respondents for clarity.

3.2.1 Key Theme 1: The Research and Publishing Culture

Under the main theme of the research and publishing culture (Table 1), there were three recurring sub-themes identified as barriers to replication which were: incentives for undertaking replication research, priority of novel research, and the business model of publishing. Survey respondents believe that engaging in open science, or conducting replication studies, will be detrimental to career progression due to lack of incentives. Sports and exercise science researchers feel pressurised to produce a high quantity of research studies due to a high level of competition for career and funding opportunities. Furthermore, according to respondents, novel research is prioritised over studies that are methodologically sound, and this is exacerbated by journal bias.

Journals were described as a barrier to reproducible research by actively promoting the file drawer issue, as they often reject research which is not considered novel or is non-significant. Researchers also expect to be “criticised” for publishing replication studies and feel there is no value placed on them, especially in higher-ranked or prestigious journals i.e., quartile 1 journals. Additionally, researchers feel that journals are a barrier to reproducible research as scientific publishing is a billion-dollar business now. Lastly, they believe publishers are often profit focused and publication fees further exacerbates the file drawer problem as unfunded researchers will simply not publish.

Table 1. **Key theme 1: The Research and Publishing Culture**

Sub-theme	*Question code*	*Quotes*
Incentives for undertaking replication research	Factors that could improve reproducibility and replicability	"If the culture changes that you should every now and then replicate a study just like you should review papers, then you might get a more actively reproducing/replicating community. For now, there simply is no individual benefit and in fact, you'll probably 'get behind' in your own publications so it may even be detrimental for your career."
	Failure to replicate or reproduce findings is a major problem	"The problem is that it is almost impossible to publish replication studies in high quality (e.g., Q1) journals - if we can't publish replication studies, there is limited incentive to conduct them as researchers"
	Existing journal efforts and why they help or not	"Most academics are incentivised by what will get them promoted. We need to include Open Science practices in promotion criteria. For example, has the candidate submitted a Registered Report in the last x years? how many of their studies have been pre-registered? how many of their studies have shared code/data? etc. Only then will many academics take Open Science/replication seriously. It's sad that academics have to be externally motivated like this, but unfortunately that is what it will take."
	Factors that could improve reproducibility and replicability	"Pressure to publish/get funding which then means replicability studies are not as valued by employer"
	Barriers to implementing changes	"The cultural inertia of previous practices has been somewhat of a barrier. It's hard and uncomfortable for people to acknowledge that the work they may have done in the past is not of the best quality and changing practices is an explicit acknowledgement of that."
	Barriers to implementing changes	"We'd need to see structural changes within universities where studies with larger sample sizes, requiring longer data collections, and therefore fewer publications was rewarded (e.g., considered for tenure track, promotion, hiring, ranking, for funding etc). But currently, academics are rewarded for being prolific with less emphasis on quality. I think journals requiring/rewarding replication and/or reproduction would also go a long way."
	Factors that could improve reproducibility and replicability	"Convincing journals of the need to change is the most difficult, because there's very little incentive for the editors and/or the publisher to change."

Table 1. Key theme 1: The Research and Publishing Culture (continued)

Sub-theme	*Question code*	*Quotes*
	Existing journal efforts and why they help or not	"I don't think journals do enough to help provide a platform for better replication but like with peer-review and the fact that they drive a model of work that is largely underpinned by volunteers providing content and volunteers reviewing content, there is nothing to force them to change."
	Failure to replicate or reproduce findings is a major problem	"Scientific replication isn't 'sexy,' or well-funded (as far as I know) so researchers don't have much incentive to replicate studies. Funding is given for new research."
	Factors that could improve reproducibility and replicability	"I'd like to emphasize that lack of incentive (funding/time, but also the added benefit for your career) is an important reason for the low effort put in reproducing or replicating the work."
	Barriers to implementing changes	"Almost all of the strategies (for improving the replication crisis) listed above come at an increased labour/logistics cost. This increased science labour/logistics must come with a commensurate increase in resources."
Incentives for undertaking replication research	Factors that could improve reproducibility and replicability	"It comes down to university-based metrics. In sports science, reproducibility-based studies do not attract funding or citations. We have to go out of our way to do this research. While important, unless it is recognized and rewarded by the university, it is very difficult to do."
	Barriers to implementing changes	"Time. It takes longer to do things 'properly'"
	Barriers to implementing changes	"Already science occurs on a tight budget. Scientist's altruism is already exploited (in terms of salary for young scientists). You want to end the replication crisis: then establish the protocols and allocate resources commensurate to the increased labour/logistics."
	Factors that could improve reproducibility and replicability	"Build the issue into funding, publications and importantly university appraisal/targets etc. if I have to double my time in an experiment because I always need to do a specific replicability study my university needs to realise, I may produce less volume overall"
	Factors that could improve reproducibility and replicability	More robust design is somewhat linked to professional incentives in the sense that robust research designs are invariably more expensive to implement, and thereby require funding bodies to recognize that one study with 100 subjects may well be worth more than 3 studies with 30.

Table 1. Key theme 1: The Research and Publishing Culture (continued)

Sub-theme	*Question code*	*Quotes*
Priority of novel research	Failure to replicate or reproduce findings is a major problem	"We are told from early on in our careers that your research must be 'novel' so I don't know of anyone reproducing or replicating studies - I am not sure they would be published. I think then that may lead to results from single studies being taken as 'true' and you also end up with lots of review articles/meta-analyses trying to make sense out of a lot of studies that are all different."
	Level of replication in my field compared to other fields	"There is such a high focus on publishing "new" results that we do not sufficiently consider the accuracy and generalizability of prior results. Even with good intentions, so much existing work is very software intensive --- so, mistakes happen. And many mistakes are just not found"
	Failure to replicate or reproduce findings is a major problem	"As before, research rewards accrue to those doing novel studies."
	Barriers to implementing changes	"As noted previously, most journals only want to publish "new" methods. I'm not aware of ANY journals in my field that would welcome a reproducibility or replication study. It would be rejected outright as "not novel.""
	Existing journal efforts and why they help or not	"I have had papers rejected on the basis that 'the results weren't 'positive' or 'significant'. We all have. Journals perpetuate the problem by prioritizing novel findings."
	Failure to replicate or reproduce findings is a major problem	"Replication studies are not favoured in science currently. It's all about the next new and best thing."
	Existing journal efforts and why they help or not	"As with the funding, we know that reviewers are seeking novelty in the work, and I would expect to be criticised if I submitted a replication study."
	Existing journal efforts and why they help or not	"As I have previously stated, replication studies are discouraged by journal editors and frequently rejected without being reviewed. This fact leads funding entities and labs to avoid the reproducibility of existing research, mainly because they do not consider it innovative and susceptible of scientific breakthroughs. Sadly, the vicious circle in Sports Sciences is not favourable for reproducibility."

Table 1. Key theme 1: The Research and Publishing Culture (continued)

Sub-themes	*Question code*	*Quotes*
The business model of publishing	Existing journal efforts and why they help or not	"Having experienced several rejections of studies that were similar to previous works, it seems that "impact factor" is driving most journals. In addition, the increase in the number of journals with publication charges is turning the scientific world into the business world. Some of these page changes are astronomical and well beyond the means of typical researchers in the field of exercise science."
	Existing journal efforts and why they help or not	"Publishers are leeches, who care nothing more than making a profit. Token gestures of encouraging open access and data deposition are hollow at best. They do not help"
	Existing journal efforts and why they help or not	"Generally, rigorous peer review and editorial handling goes a long way. However scientific publishing has become a billion-dollar business with way, way too much financial dependence and consequently a flood of low-quality and predatory journals publishing poor science."
	Factors that could improve reproducibility and replicability	"Take the politics out of science."
	Existing journal efforts and why they help or not	"All journals want to do is increase impact ratings"
	Barriers to implementing changes	"As mentioned, before I believe that academia pushes for greater scientific output at the cost of its quality"
	Existing journal efforts and why they help or not	"Way too much nepotism in review process. Poorly designed/described studies are often published purely because of a well-known co-author (who likely had very little to do with the study."

3.2.2 Key Theme 2: Educational Barriers to Research Integrity

Under the main theme of educational barriers to research integrity (Table 2), there were two recurring sub-themes which were: quality of peer review, and statistical expertise and knowledge of researchers. There were mixed views on the role of peer review for upholding values of research integrity, yet there is agreement on the importance of statistical knowledge for peer reviewers. Respondents identified greater scrutiny is needed by peer reviewers on study design. However, a lack of a formalised education process or screening for peer reviewers has led to the inability of some reviewers to assess poor analyses, lack of controls, or to recognise bias. Statistical expertise was a clear recurring theme throughout many responses, specifically researchers' statistical education. Many researchers feel that a better understanding of study design, and the use of different statistical techniques to analyse data, would improve reproducibility and replicability within the field. Errors with data management and statistical techniques application were discussed as common factors that affect reproducibility and replicability of this field.

306 **Table 2. Key theme 2: Educational Barriers to Research Integrity**
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Sub-theme	*Question code*	*Quotes*
Quality of peer review	Existing journal efforts and why they help or not	"The peer review process is only as good as the peer reviewers. I've read many studies with missing details."
	Existing journal efforts and why they help or not	"Methods are reviewed at a level that is deemed "peer review". However, given my personal experience of peer review and papers that have been sent to me by journals, many papers sent by so called "top journals" fall outside specialist areas and deemed "expertise". This is before we consider the lack of general understanding for statistics within the field of exercise sciences. Which open up levels of bias, poor analysis, lack of controls..... The list is endless here as to why replication or repeating findings would be an issue."
	Factors contributing towards a failure to reproduce or replicate	"Sometimes the research is so badly written that it is hard to understand important parts of the research/test/experiment. This could go under insufficient peer review, but often conference papers (which are still indexed) are lazily peer-reviewed."
	Existing journal efforts and why they help or not	"I believe it comes down to the reviewer. Many reviewers miss issues within methodologies and therefore this issue continues."
	Factors contributing towards a failure to reproduce or replicate	"Authors and reviewers pretending they know the technical procedures. They make wrong interpretations of the phenom and bring low contribution to science"
	Existing journal efforts and why they help or not	"I also encounter editors and reviewers insisting that hypotheses are added after submission if not present. Reviewers also influence authors to adopt their (reviewers') conventions, style, rules, etc. which leads to a slow evolution of arbitrary practices."
	Existing journal efforts and why they help or not	"It's all well and good having checklists but editors need to listen to reviewers (like me) who flag up dodgy studies rather than ignore and publish them just because they are sexy"

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Table 2. Key theme 2: Educational Barriers to Research Integrity (continued)

Sub-theme	*Question code*	*Quotes*
Statistical expertise and knowledge of researchers	Factors contributing towards a failure to reproduce or replicate	"I think many times researchers believe that they know more about research than they do, making serious errors in methodology, using the wrong statistical tests, or not having clear objectives that they know how to accomplish."
	Factors contributing towards a failure to reproduce or replicate	"I guess many researchers simply underestimate (just like I did for a long time) the role of chance for obtaining seemingly significant results, particularly when you combine low power and researcher degrees of freedom. Stuff becomes significant by chance, and then of course you cannot replicate it."
	Factors that could improve reproducibility and replicability	"I believe that improving research education is the key, improving statistics education is vital, and above all improving research ethics, since there are researchers who think that the data should say what they want and that is why they review and modify them until they get what they want. In those cases, replicability is impossible.**"**
	Factors contributing towards a failure to reproduce or replicate	"Lack of understanding of statistical methods to analyse data."
	Factors contributing towards a failure to reproduce or replicate	"I think that most students, and therefore advisors, rarely explore their data adequately before thesis and publishing due to pressure to publish and complete. I think many blunders would be avoided, especially failures to detect differences, and insights into the nature of the data would better inform the approaches for analysis. Perhaps a data scrubbing to data exploration module could be produced. Also, I have witnessed many cases of research assistants not using the actual protocol in clinical RCT sport science studies resulting in lots of variance in the data."
	Factors contributing towards a failure to replicate	"Investigator/researcher laziness or sloppiness/short cuts"
	Factors contributing towards a failure to replicate	"There are many but ability to recruit larger numbers of participants who fit study criteria, human biases in a number of aspects of the research, poorly reported methodology in the literature which we cannot replicate, poorly performed or incorrectly reported statistical analysis that we cannot replicate etc"

Table 2. Key theme 2: Educational Barriers to Research Integrity (continued)

Sub-theme	*Question code*	*Quotes*
	Factors that could improve reproducibility and replicability	"Errors in data management (cleaning, accounting for missingness, coding variation between statistical software) and important differences in the data are both potential issues. Actual variation in reality is always a contributor. Measurement and misclassification."
Statistical expertise and knowledge of researchers	Factors contributing towards a failure to reproduce or replicate	"There is a need to educate existing researchers - perhaps by holding workshops at conferences on methodology, rather than just on results, and also, encouraging journals to publish papers or perspectives on clinical trial methods. for example, encouraging journals to consider really well-designed pilot studies as "real" research. Having time or money to replicate findings or mentor students won't work if you are not using the right methods in the first place."
	Level of replication in my field compared to other fields	"Typically, we publish small sample size research, but most researchers are too statistically innumerate to analyse and interpret data accordingly."

3.2.3 Key Theme 3: Research Responsibility to Ensure Reproducibility and Replicability

Under the main theme of research responsibility to ensure reproducibility and replicability (Table 3), there were three recurring sub-themes: journal responsibility, researcher responsibility, and senior researcher/supervisor responsibility. The ownership of responsibility to ensure reproducibility and replicability in the research process was heavily debated in the responses.

Some believe journals are responsible for promoting transparency; there should be basic criteria for sample size justification, reporting and analysis, and flexibility with journal article length would be helpful. As we move into a more digital era, researchers appear frustrated with the lack of a corresponding increase in page limits which would decrease the selective reporting of results. Journals can facilitate and encourage open science practices via author guidelines, types of publications requested i.e., replication studies, and can enforce reporting criteria for readers and authors. Essentially, they have an opportunity to be leaders in implementing policies; they should be fostering changes rather than just policing. On the other hand, some researchers feel that journals have too much research power; they should have a smaller role rather than act as gatekeepers in science.

Some respondents believe that the responsibility for ensuring reproducibility and replicability should be with the researchers. Publication is the last stage of the research process, so it is the researcher's responsibility to maximise transparency in their reporting practices and appropriately design their studies. Finally, supervisors were specifically identified as having a responsibility to promote open science practices for reproducible and replicable research with early career researchers and students. The promotion of these practices by the supervisors appears to determine the engagement of other researchers within the laboratory or research group according to respondents.

Researchers in the field also believe that individuals overestimate the level of statistical expertise they have. Some theorize that this applies to both early career researchers and supervisors. Supervisors also have an important role as mentors and should educate themselves, and their students, on the importance of reproducibility and replicability.

Respondents believe more collaboration with statisticians and data analysts would be helpful to improve their own knowledge and account for any shortfalls in their knowledge that could affect research transparency and quality.

Table 3. Key theme 3: Research Responsibility to Ensure Reproducibility and Replicability

Sub-theme	*Question code*	*Quotes*
Journal responsibility	Existing journal efforts and why they help or not	"Reporting requirements do not seem to be consistent across journals."
	Existing journal efforts and why they help or not	"I think that by the time a journal imposes guidelines related to reproducibility/replicability, it is too late, because the project has already been done and the manuscript written. These directions should come from funding agencies and research institutions."
	Existing journal efforts and why they help or not	"I think the journal publishers are using standards/checklists developed by the scientific community, because the community is demanding more transparent reporting. I don't think it is the journals responsibility. I think the researchers should own and drive it."
	Existing journal efforts and why they help or not	"The journals wield a double-edged sword when it comes to replication and reproducibility. On the one hand, reporting guidelines in most journals I have experience with seem to overall have a positive effect on reproducibility and replicability. However, journals seem to reject papers that disseminate the replication of a study, thus preventing an objective test of the replicability of any study."
	Existing journal efforts and why they help or not	"As per previous answer, journals are gatekeepers to much of what we publish as scientists. We are bound by their rules (preprints being the exception). I believe journals should make much more effort to improve transparency and openness of research published in their journals."
	Existing journal efforts	"I'm not sure this is something a journal publisher should be responsible for. I think this should be core to the scientific community."
	Existing journal efforts and why they help or not	"Reporting requirements do not seem to be consistent across journals."
	Existing journal efforts and why they help or not	"The bigger issue is article length. So much effort goes into writing 'objective' papers with brief method sections that the nuance about what, when, and why certain decisions made can't fit into the paper, which fuels the crisis."

Table 3. Key theme 3: Research Responsibility to Ensure Reproducibility and Replicability (continued)

Sub-theme	*Question code*	*Quotes*
Journal responsibility	Level of replication in my field	"My concern is more related to the level of detail provided in the methods section. Exercise can be highly variable, and authors (and reviewers) aren't doing a great job of ensuring that enough methodological detail is provided so that studies can be replicated. You can't replicate a study if you aren't positive what is being done. This is also similar for reporting of participant characteristics or handling of blood/tissue samples."
	Existing journal efforts and why they help or not	"While it is important to enforce reproducibility and replicability, I struggle to see how journals can enforce this."
	Existing journal efforts and why they help or not	"Journals are a barrier to reproducible research, actively promoting file drawer problems and having statistically naive editors."
	Existing journal efforts and why they help or not	"Journal can certainly facilitate good open science practices among academics via their author guidelines, expectations, types of publications, etc. I think the sport and exercise science journals are still playing catch-up to journals in other fields though (e.g., psychology)."
	Existing journal efforts and why they help or not	"Academic journals have an opportunity to be a leader in the space of reproducibility and replicability by implementing policies for authors to abide by in submitting their work."
	Existing journal efforts	"As with funding agencies, I think this is looking in the wrong place for a solution."

Table 3. Key theme 3: Research Responsibility to Ensure Reproducibility and Replicability (continued)

Sub-theme	*Question code*	*Quotes*
Researcher responsibility	Level of replication in my field compared to other fields	"Variability in the choice of research participants, research settings, the amount of confounding variables that researchers are confronted with, the changes in sport participation rules and conditioning techniques, etc, are all factors that negatively influence the reproducibility or replicability of study findings and results in the sports science field."
	Level of replication in my field compared to other fields	"Exercise science seems to be behind other fields, like psychology in addressing this issue. We seem to be complacent with the status quo of low sample sizes, poor descriptions of methods, and publication bias towards novel findings. Frankly, it makes us look bad."
	Existing journal efforts and why they help or not	"At the point of publication, it should not be expected that authors return back to data collection. However, if a journal changes their requirements, then researchers would be aware early on in project design and data collection that reproducibility is required. This will take a gradual shift in the journal acceptance requirements as projects are years in the making before publication."
	Level of replication in my field compared to other fields	"Most people don't understand the scientific process, and most don't understand how context or study design dependent outcomes can be"
	Barriers to implementing changes	"Lack of time, lack of expertise on how to implement this, and lack of support/reward for these kinds of efforts. Doing your part is not rewarded, and there don't seem to currently be any negative consequences for not complying with best practices."

Table 3. Key theme 3: Research Responsibility to Ensure Reproducibility and Replicability (continued)

Sub-theme	*Question code*	*Quotes*
Senior researcher responsibility	Barriers to implementing changes	"Some older "traditionalist" colleagues prefer not to change the ways of assessment, conducting and writing studies."
	Barriers to implementing changes	"Other faculty members and students are not always responsive"
	Barriers to implementing changes	"The PI [principal investigator]. In North America, all "trainees" working under a PI can only do as much as the PI supports. There is a huge power imbalance that can be very difficult to navigate for more junior colleagues if the PI is not interested, dismissive, and in some cases hostile to such practices. This has been my experience (but I also know of several PIs who are supportive).
	Factors that could improve reproducibility and replicability	The PI is often the source of the problem. Who mentors them?"
	Barriers to implementing changes	"A big one is collaborating with colleagues who don't have the same values. We either have to not collaborate with certain people, try to convince them of the benefits of publishing fewer studies per year, or agree then we go outside the lab group people have different research norms."
	Barriers to implementing changes	"Poor acceptance from laboratory heads on the importance of such work."
	Factors that could improve reproducibility and replicability	"*Explicitly* encouraging reproducibility and replicability would make a difference, rather than teaching students that all their work must be new and novel"
	Factors that could improve reproducibility and replicability	"Mentoring of students, graduate students, post-docs in all aspect of quality research."

3.2.4 Key Theme 4: Current Practices Facilitating Reproducibility and Replicability in the Field

Under the main theme of current practices facilitating reproducibility and replicability in the field (Table 4), there were two recurring sub-themes which were: data sharing and checklist usage. There appears to be mixed views on open data or data sharing from researchers in the field; journals are encouraging data sharing, which is deemed positive, but there is little enforcement or standardisation of this. Many respondents have concerns with data sharing; there are potential career disadvantages to forcing all data and code to be shared, for example, some authors fear being "scooped". Secondly, for the author, open datasets are time consuming because they must be organised in a readable format.

Finally, respondents believe it difficult to ascertain whether data badges and sharing are having a positive effect, therefore, they are unsure whether they are worthwhile. There is also a general sense of frustration with the use of checklists when submitting research for publication. Respondents feel they are currently too generic, applied inconsistently and without rationale, and are frequently ignored during the peer review process. Some researchers feel they should be compulsory, and the study should not be published if the checklists are not followed appropriately. Contrastingly, many respondents declared they should be banned altogether.

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Sub-theme	*Question code*	*Quotes*
Data sharing and availability	Existing journal efforts and why they help or not	"While some journals explicitly advise authors to do x or y, often they do not enforce, which means that authors ignore the recommendations."
	Existing journal efforts and why they help or not	"Making data sharing compulsory would be a major step forward. Many journals state this is a requirement but do not enforce this."
	Existing journal efforts and why they help or not	"Depositing datasets in data repositories (I mostly use our own institutional repository) and making them accessible in publications has been helpful. However, the act of creating these datasets in ways suitable for sharing is very time consuming and challenging when time/funding are limited."
	Existing journal efforts and why they help or not	"The only effort I have encountered is a requirement to provide data open access on acceptance, which I think might have some role in deterring people from actively making up data. I think we can't ignore the potential career disadvantages in forcing all data and code to be shared: Particularly for smaller/less well-funded groups, having to 'give away' work that they would otherwise be able to leverage to get a head start on future publications to bigger (and hence faster-moving) groups is a real problem (which gets shouted down when we are banging the drum for 'open science')."
	Existing journal efforts and why they help or not	"Collecting the data is hard work and expensive. Immediately giving away those data can deter a lab's ability to be successful, if other labs end up publishing new analysis of those data before your own lab gets the chance."
	Existing journal efforts and why they help or not	The "open data" concept also claims to be for the public good. But beware: information curation platforms will capture these commons. Just look at Facebook/Google/Etc. On the scale of a civilization, an entity that controls access to information can manipulate the data without owning the data."
	Existing journal efforts and why they help or not	"I have been pleased to discover opportunities to submit registered reports, receive pre-registration badges, and share data. I am unsure if these opportunities are having a positive effect, and I think journal publishers should do more to encourage reproducibility and replicability because I still read articles that seem to describe questionable research practices."

Table 4. Key theme 4: Current Practices Facilitating Reproducibility and Replicability (continued)

Sub-theme	*Question code*	*Quotes*
Checklists	Existing journal efforts and why they help or not	"Journal checklists are overly generic which impedes their utility. Making them more extensive is not useful and would drive me crazy, especially for a desk-reject."
	Existing journal efforts and why they help or not	"More work needs to be done in a fostering manner rather than a policing manner. Checklists are inadequate to deal with the issue."
	Existing journal efforts and why they help or not	"Checklists are useless. So are requirements to use e.g., non-parametric statics or report an effect size, which I have seen. People just google a non-parametric test, run, and interpret it just as blindly as they did any other. Same for the effect size. Same goes for reviewers."
	Existing journal efforts and why they help or not	"I think that the checklists are not enough and most times not mandatory. It would be better to be more rigorous in the methods section revision and ask the authors to share more detailed information on how the study was carried."
	Existing journal efforts and why they help or not	"The implementation of and adherence to checklists and standards is very haphazard."
	Existing journal efforts and why they help or not	**"**Methods checklists, sources for research materials, and the requirement to have all raw data in a public repository or as supplemental files are extremely useful. It does need to be enforced better, and standardization is currently lacking."
	Existing journal efforts and why they help or not	"Some journals attempt to enforce standards around sample sizes, reporting, and analysis procedures which does help in terms of planning an appropriately sized/powered study, which in term will help with replicability. However, this does need to be more consistent across journals, and also needs to be accompanied by a change in culture (collaboration, time, less pressure to publish) in order to be successful."
	Existing journal efforts and why they help or not	"Mandatory open data and open code, statements regarding researcher degrees of freedom, justification of sample sizes (and others) "force" authors to consider these things."

Lastly, and although not specifically linked to the themes identified in the thematic analysis, there were multiple comments regarding the attitude towards open science as a movement (Table 5). Some respondents believe a few open science advocates are actively trying to discredit other researchers' work or specifically targeting research groups. Others reported the negative perception around failed replication studies discourages them from attempting replication.

Table 5. Other comments on the attitude towards the open science movement

Question	*Quotes*
What barriers would prevent you from volunteering in a large reproducibility or replication project?	"Some of these projects come off as "witch hunts" unless proper safeguards are in place. There are many biases in our field. One group could make an effort to single out another group. I would hope this wouldn't happen, but that is why I would carefully evaluate the effort before agreeing to participate [in a replication project]."
Factors that could improve reproducibility and replicability	"Reduce the negative stigma of having a result that is not replicable, and emphasize the opportunity to sort out what is going on."
What barriers would prevent you from volunteering in a large reproducibility or replication project?	"Time and effort versus the benefit. Sports science isn't cancer biology if the findings of a study are questionable, they can simply be ignored, they don't have to be proved wrong – it's not life or death!"

4 Discussion

The overall aim of this study was to determine the attitudes towards, and perception of, reproducibility and replicability in sports and exercise science researchers. Survey results showed three-quarters of the respondents believe there is a crisis of reproducibility and replicability in the field, while 42.5% believe this crisis is significant. The concerns regarding replicability and reproducibility are lower than those of Baker & Penny, (2016) where 90% of researchers across different scientific disciplines acknowledged the existence of a reproducibility crisis. We expect the lower rate of concerns reflect the minimal discourse on replication in sports and exercise science. Additionally, the potential naivety that science is functionally well in the field, despite identified concerns among some researchers, could have contributed to this lower rate. Four key themes were also generated in the thematic analysis: the research and publishing culture, educational barriers to research integrity, research responsibility to ensure reproducibility and replicability, and current practices facilitating reproducibility and replicability, which we have interpreted and grouped in the results. Therefore, the remainder of this section will discuss the context and implications of these thematic areas, as well as suggestions for future practices.

As identified in the theme of the research and publishing culture, researchers feel that sport and exercise science is currently under siege from competition, commercialisation and metrics. These create a research culture that is largely driven by career incentives and novel research (Nosek, Spies and Motyl, 2012; Chambers *et al.*, 2014; Smaldino and McElreath, 2016). The pressure to publish is exacerbated by competition within academia*;* there are more PhDs being produced in world universities than there are permanent academic positions (Powell, 2015). Publication influences hiring, promotion and grant decisions which are considered a marker of achievement (Fanelli, Costas and Ioannidis, 2017), consequently, the publication process is negatively perceived by some researchers due to overwhelming academic pressure (de Vrieze, 2021).

Academic pressures are similarly apparent in sports and exercise science as “pressure to publish” was identified as one of the highest contributing factors towards a failure to replicate or reproduce findings in our survey (Figure 2). This is unsurprising given the survey respondents feel pressure to produce a large quantity of research output, potentially without

regard for the quality or transparency of that research to keep up with their peers. Furthermore, 62.8% of clinical cancer researchers admit publishing pressure influences their reporting while 23% believe selective reporting or manipulating data was necessary to prove a hypothesis (Boulbes *et al.*, 2018). One could argue that our field could be suffering from the same assumption, and we may have a crisis of *incentives* on our hands.

Sports and exercise science researchers reported they are disincentivised to undertake replication studies due to the priority of novel research and the belief that replications lack creativity ("*we know that reviewers are seeking novelty in the work, and I would expect to be criticised if I submitted a replication study*"). This finding is similar to other fields (Nosek, Spies and Motyl, 2012), therefore, these researchers are as much victims as they are facilitators of poor scientific behaviours. They are incentivised to engage in poor, or potentially dishonest, practices (i.e., questionable research practices; John et al., 2012) simply because of the trade-off between quantity and quality in sports and exercise science, of which quantity is winning (Allen and Mehler, 2019) ("*I believe that academia pushes for greater scientific output at the cost of its quality*"). There needs to be a change in culture for individuals.

A healthy research culture, which rewards quality rather than publication volume, would improve replicability and reproducibility within the field. These are not simple changes; they require structural changes at a cultural, university and publishing level. Achievable changes can be made in the short term, which will set the foundations for improved culture practices in the future. Examples of these changes include organising a journal club to discuss open science practices, preregistering studies, adopting preprints, using a dedicated and transparent project workflow system etc. The adoption of open science can be overwhelming as it has many different facets, but Kathawalla et al., (2020) created a helpful guide to assist students and advisors with their journeys into open science. The current accepted norms of pressure to publish will continue until the incentive structure changes within the field.

For researchers, there is a temptation to produce and prioritise work which is novel for career success (Chambers *et al.*, 2014). Novel or impressive findings are a primary goal of the current academic culture (Bernards *et al.*, 2017). This is evident by the 2500% increased frequency of words such as "innovative", "novel" and "ground-breaking" in abstracts of PubMed articles from 1974 to 2017 (Vinkers, Tijdink and Otte, 2015). The demand for novel research is also apparent in our field and it instils a need for researchers to produce statistically significant

findings. According to our survey respondents, selective reporting of novel or positive results was one of the highest contributing factors towards a failure to reproduce or replicate studies (Figure 2). This is supported by the implausibly high positive result rate of 81% across 300 studies in three flagship sports and exercise science journals (Twomey *et al.*, 2021). Similarly, a positive result rate of 82% was reported for four high impact sports medicine and physiotherapy journals (Büttner *et al.*, 2020). Many clinical cancer researchers (47%) also felt pressured to produce a "positive" result by a collaborator (Boulbes *et al.*, 2018), and based on our survey responses, this proportion could be higher in our field.

Non-significant or less "exciting" results are often shunned by journals due to lower citation practices (Fanelli, Costas and Ioannidis, 2017). A consequence is that sports and exercise science researchers are possibly disinclined to submit these types of results for publication, and they are relegated to the "file drawer" (Rosenthal, 1979). Significant, novel findings are therefore "worthy" of publication while null or less exciting results will not be observed by the scientific community ("*I have had papers rejected on the basis that the results weren't 'positive' or 'significant'. We all have. Journals perpetuate the problem by prioritizing novel findings.").* Publication bias can alarmingly distort the proportion of true effects in the literature body rendering many study findings non-replicable.

The crucial step of verification or replication is rarely taken in sports and exercise science while journals are breeding poor scientific behaviours (Chambers *et al.*, 2014). However, changes are ongoing to prevent selective reporting of results as Registered Reports are now offered as a publishing format (Chambers *et al.*, 2014). Registered Reports undergo two rounds of peer review, before and after data collection, so that the manuscript could have an in-principal acceptance before any results are obtained. Although this format of publication is offered by many journals (see cos.io/rr), it is only beginning to be offered by sports and exercise science journals (Impellizzeri, McCall and Meyer, 2019; Abt *et al.*, 2021). Sport and exercise science must undertake a collective effort, where possible, to support journals who promote open practices and guidelines, rather than a focus on profit or their impact factor, a controversial metric (Heathers and Grimes, 2022). This may be easier for those who have more career security e.g., tenured researchers, and leadership from these more senior researchers on this issue would greatly improve adoption of better publishing practices.

Statistical education was a key recurring theme throughout the thematic analysis and is supported by the quantitative results as respondents selected poor experimental design, inadequate mentoring, low statistical power, and mistakes as contributing factors towards a failure to replicate. Statistical and methodological errors are prevalent in sports and exercise science (Knudson, 2005; Nielsen *et al.*, 2018; Borg, Lohse and Sainani, 2020). The use of controversial statistical methods even resulted in mainstream media criticism (Aschwanden and Nguyen, 2018; Sainani *et al.*, 2019). Consequently, some researchers advocate for increased collaboration with statisticians within the field and we echo those calls (Sainani *et al.*, 2021; Sainani and Chamari, 2022). This recommendation requires a shift in the culture norm, but perhaps larger structural changes are required for the long-term health of the sports and exercise science academic system. A redirection of attention to the impact of open science practices on students could be instrumental for the future of our field (Pownall *et al.*, 2022). The introduction of preregistration was perceived as a helpful planning tool in the education of undergraduate psychology students and could promote best research practices, thereby reducing questionable research practices (Blincoe and Buchert, 2020). Similarly, replication studies could be encouraged as part of student projects (e.g., the Hagen Cumulative Science Project, (Jekel *et al.*, 2020); and the Collaborative Replications and Education Project, (Wagge *et al.*, 2019)).

When replication studies are integrated as part of academic training, students report an increased understanding of the research process, increased confidence with statistical methods, and find the overall experience quite positive (Stojmenovska, Bol and Leopold, 2019; Smith, Yu and Schmid, 2021). The incorporation of reproducible and replicable practices by early career researchers could improve the outlook of sports and exercise science by positively influencing the accuracy of reporting, which respondents identified as problematic for research quality ("*I think many times researchers believe that they know more about research than they do, making serious errors in methodology, using the wrong statistical tests, or not having clear objectives that they know how to accomplish.*"). Prioritisation of statistical education may also have a positive impact on peer reviewers when early career researchers eventually assume this role. Therefore, the sports and exercise science field will reap the reward of an investment in better statistical education in the future.

There were mixed views on the responsibility of sports and exercise science journals for ensuring reproducibility and replicability. Some respondents believe journals should promote

reproducibility and replicability (*"Journals can certainly facilitate good open science practices among academics*"), while others believe researchers are responsible ("*I think the researchers should own and drive it*"). Reporting guidelines and checklists were introduced by journals over a decade ago (Atkinson, Batterham and Drust, 2008), although they do not appear to be used frequently (Twomey *et al.*, 2021), even though their use was shown to increase the quality of reporting in medical journals (Turner *et al.*, 2012). The Transparency and Openness Promotion (TOP) guidelines were created by the Center for Open Science to enhance journal transparency (Nosek *et al.*, 2015). The mean TOP factor (https://osf.io/t2yu5/) for 38 sports and exercise science journals was 2.05 ± 1.99 out of 27 for engagement with openness and transparency (Hansford *et al.*, 2022). This low score demonstrates an opportunity for these journals to review their open science policies and implement changes to increase transparency and move the sports and exercise science field forward. There was a clear consensus in the responses that journals are almost sole gatekeepers in science as they have a large proportion of research responsibility but frequently reject replication studies ("*The journals wield a double-edged sword when it comes to replication and reproducibility*").

We, as sports and exercise science researchers, need to assume responsibility of our study design(s) rather than expecting improvements to be suggested during the peer review process. Peer review is not designed to verify findings; that expectation is too much for a voluntary role (Mellor, 2021). Even if it was, it is only possible if the data and code are shared. As this is not the norm in sports and exercise science (Borg *et al.*, 2020), peer reviewers are limited to reviewing the claims based on the limited information provided in the manuscript. We suggest spending more time and attention on our study design e.g., pre-study power calculations (Scheel *et al.*, 2020; Mesquida *et al.*, 2022), undertake preregistration and specify our hypotheses (e.g., on https://osf.io/ or https://sportrxiv.org/index.php/server), and collaborate with statisticians to improve our statistical inferences (Sainani *et al.*, 2021). Essentially, we must assume responsibility for reproducibility and replicability ourselves, as opposed to offsetting the responsibility elsewhere (i.e., peer reviewers).

Like reporting guidelines and checklists, data sharing guidelines are present in many sports and exercise science journals. Although, data sharing would facilitate reproducibility and replicability, the guidelines are not often enforced according to survey respondents ("*The implementation of and adherence to checklists and standards is very haphazard*"). Of 300 sports and exercise science articles, only 2.33% had a data accessibility statement while 0.67%

reported open data or code (Twomey *et al.*, 2021). In a similar analysis of 299 sports and exercise science studies, only 4.3% of 299 articles shared data while 1.7% stated data was available on request (essentially meaning no data is available; Gabelica et al., 2022), and no study shared any code or syntax related to the statistical analysis (Borg *et al.*, 2020). There is some reluctance to share data due to concerns regarding *"*scooping", where another author or research group obtains the data and publishes first ("*...having to 'give away' work that they would otherwise be able to leverage to get a head start on future publications to bigger (and hence faster-moving) groups is a real problem").* This concern is shared by researchers in other fields, who view open data access as a beneficial process for the development of the scientific system of knowledge but not for an individual researcher and their prospective career (Ostaszewski, 2014).

Researchers are fearful that open data might lead to misuse or misinterpretation of that data (Ostaszewski, 2014). Yet, as data and code availability are essential for future replication and meta-analyses, identifying errors during the scientific process must be normalised and communicated in a respectful but factual manner. We, as researchers, make mistakes (Nuijten *et al.*, 2016), and a process of long-term self-correction is important for research validity. Furthermore, citation counts are higher for studies with open data (Piwowar and Vision, 2013). There are initiatives to encourage data sharing such as open data badges and the Peer Reviewer's Openness Initiative (Morey *et al.*, 2015). Although there can be issues around data sharing (e.g., ethical considerations, intellectual property, or data is part of a longitudinal project), one could release a limited set of variables (excluding those that threaten privacy), embargo the dataset, or share a simulated dataset (Borg *et al.*, 2020). Sharing data increases its utility whereas closed science decreases its usability over time (Vines *et al.*, 2014). When data sharing is not possible, sharing of code, instruments and analytical materials are still valuable for replication and should be encouraged in sports and exercise science.

Finally, there were some comments from survey respondents about the open science movement in general. Some respondents reported a negative perception around failed replications. This indicates an increased need to educate researchers on the meaning of a non-replicable finding; it does not automatically undermine the original study results, or mean they are false (Maxwell, Lau and Howard, 2015). There are a number of reasons a replication study will have dissimilar results to the original study including: unanticipated differences in the studies, low statistical power, or large heterogeneity in effect size estimates (Klein *et al.*, 2018). Perhaps the term

"failed" should be removed from replication research altogether as it infers negativity. Regardless of the replication outcome, there must be respectful communication to original authors (Janz and Freese, 2020) and consideration of the tone of scientific critique (for further discussion see; Derksen and Field, 2022). The open science movement aims to improve the current biased and exclusive academic system (Kent *et al.*, 2022), and must be inclusive of all types of researchers: students, early career researchers and senior researchers. In other words, a shift in the current closed research culture and gatekeeping should be a goal of future researchers in this field.

5 Limitations

There are several limitations of this survey. Firstly, there was a high level of familiarity with the terms reproducibility and replicability; this indicates that the respondents were biased towards open science and were more likely to participate i.e., survey bias. The survey was specifically not advertised on social media to minimise this as best as possible, but it is highly likely that our respondents also shared an interest in this topic. Secondly, the survey was adapted from Baker and Penny, (2016) who used the terms reproducibility and replicability interchangeably. For this survey, definitions for reproducibility and replicability were given. However, for question 9 (see https://doi.org/10.17605/OSF.IO/64R8M for full survey), these constructs were ill-defined and used interchangeably. For example, question 9 states "*the results of a given study could be replicated exactly or reproduced in multiple similar experimental systems with variations of experimental settings such as materials and experimental model*". This could be viewed as misleading for the participants as the answer should reflect the union of two different constructs. Additionally, some of the Likert questions were incorrectly balanced i.e., in Figure 2 there were more options for "negative" answers than "positive". This is a limitation of the original study from which this survey was adapted that was not corrected here. Finally, the participants had the option of not answering questions with an open text box response, therefore, the respondents who had an opinion may be more inclined to answer i.e., response bias.

6 Conclusion

More than three-quarters of respondents believe there is a reproducibility and replicability crisis in sports and exercise science. In the thematic analysis, respondents believe novel research is prioritised over methodologically sound research, and publication quantity over

quality. There was a consensus that journals currently have too much research power and the guidelines/policies they have in place for increasing transparency (reporting checklists and data sharing guidelines) are not enforced sufficiently. Statistical education was also highlighted as a contributing factor towards poor reproducibility and replicability in the field. We recommend assuming increased responsibility for ensuring the reproducibility and replicability of our own work by appropriately designing studies, preregistering hypotheses, collaborating with statisticians, and sharing data. We also recommend the inclusion of open science practices as part of early career researcher education, including replication studies as a potential replacement for the traditional thesis, as well as an open mind towards other replication attempts. The strategic implementation of small changes will ultimately benefit the reproducibility and replicability of the field in the future and seeing examples of open science practices should then increase uptake, particularly amongst early career researchers in the long term.

Acknowledgements

The authors would like to thank Aaron Caldwell for his helpful feedback on the manuscript and the R code for the graphs. We would also like to thank the survey respondents for their time, particularly those who contacted us with feedback about the survey.

Disclosure Statement

The authors report there are no competing interests to declare.

Funding

This work was supported by the Irish Research Council's Government of Ireland Postgraduate Scholarship Programme (GOIPG/2020/1155).

Data Availability

The survey data, R code and supplementary materials are available online at https://doi.org/10.17605/OSF.IO/64R8M while the preregistration is also available online at https://doi.org/10.17605/OSF.IO/EXK6N.

Author Contributions

Contributed to conception and design: JM, JPW

Contributed to acquisition of data: JM

Contributed to analysis and interpretation of data: JM, JPW

Drafted and/or revised the article: JM, JPW, CM

Approved the submitted version for publication: JM, JPW, CM

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