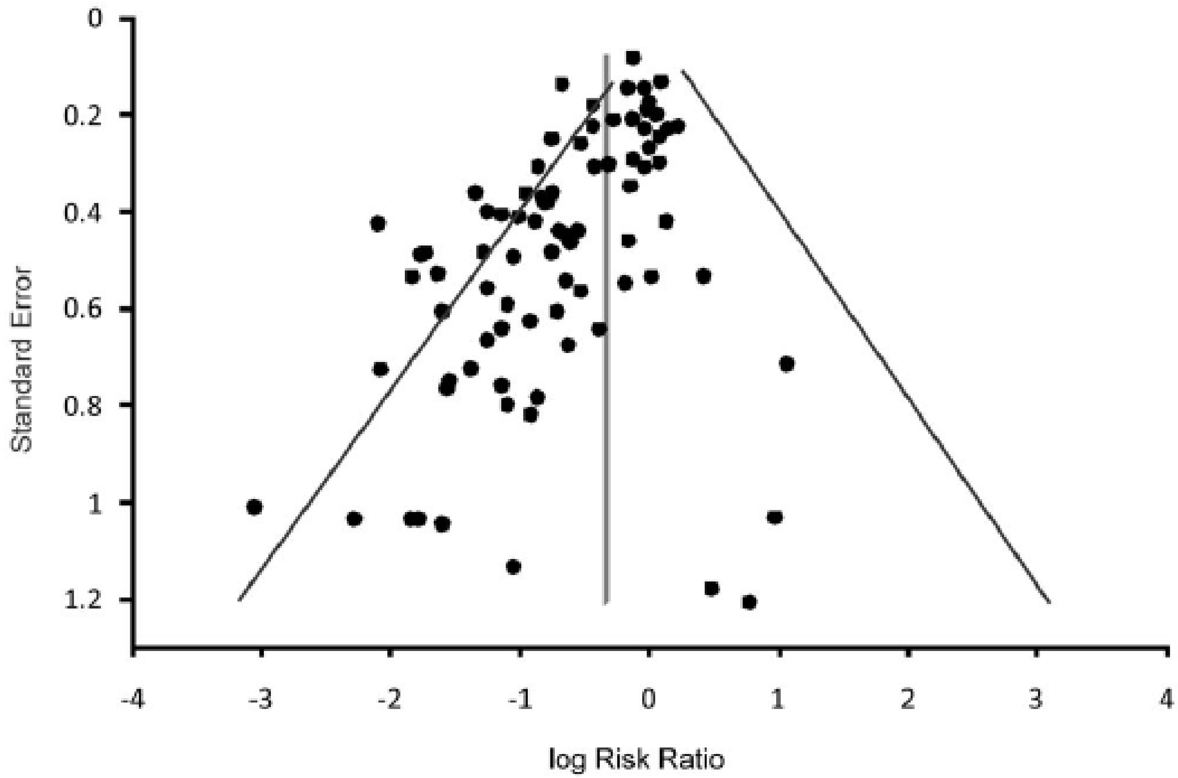
APPENDIX

Sports vision has evolved into a multidisciplinary specialty with contributions from clinicians, researchers, athletic trainers and athletes, that utilize a diverse array of technologies in both applied and real-world contexts. The emerging research that has been done in this space necessarily involves logistical and access challenges but is also greatly benefitted by the considerable data that is available to make scientific inquiries that can answer questions about the cause and effect relationships between vision and sports performance. As reviewed in the main article, there have been successes and challenges in this research to adhere to best practices for evidence-based science. Through continued evolution, researchers have begun to conduct larger and better powered studies, implemented placebo-control, pre-registered hypotheses and methodologies, and started to adhere to Open Science approaches that make the data and materials of science available to others. Despite this movement, such best-practices are the exception and not the norm. Therefore, this review has attempted to point out improvements that may move this field forward. In the following supplemental materials, we elaborate on some of the challenges that result from working with athlete populations and biases that may result. This is followed by an introduction to Open Science techniques that may continue to improve the discipline.

1. Challenges for evidence-based science when working with athlete populations

As described in this review, there is considerable variability in the sample sizes of studies that have attempted to link visual assessment and/or training with game performance. In the case of the smaller studies that may be insufficiently powered to detect effects, it is possible that they may be correct in their conclusions but may also be subsequently contradicted by additional larger studies. This phenomena is illustrated in a 2012 report by Ritchie and Romanuk[A1] that describes the "funnel" effect of probiotics within the specialty of gastrointestinal disease. In that report, and illustrated in ***Appendix Figure A1*** below, the authors evaluated the standard error of multiple reports in the field against the log Risk Ratio that compares the purported effect of a study against the sample size of the study.



Appendix Figure A1. *From Ritchie and Romanuk (2012) funnel plot illustration with gaps indicative of a potential publication bias.*

In reviewing the funnel plot, two distinct observation can be made:

a) Review of the x-axis (log Risk Ratio) illustrates that the majority of studies (each represented by a black dot) are on the left side of zero, and fewer studies are on the right side of zero. Negative Risk Ratio values would suggest a reduction in risk, or a “positive study”; whereas positive values would suggest an increased risk of gastro-intestinal disease or a “negative study”. As one can imagine, authors and journals are unlikely to publish scientific reports that make a disease condition worse and are more prone to publish reports in which a disease state is reduced or healed.

b) Secondly, as the standard error decreases (closer to zero), a greater number of studies have Risk Ratios closer to zero, or even slightly positive. This suggests that as studies with larger numbers of participants are published, the bias towards negative Risk Ratios is reduced. As such, it can be inferred that larger studies tend not to show the effects commonly reported in smaller studies.

Both observations are important in considering the possible propensity towards small study sizes in research with athlete populations. As such, it may be preferable to make smaller, sufficiently powered incremental additions to the sports vision literature instead of pursuing studies that attempt to make sweeping claims. The concept of "aggregation of marginal gains" describes this approach. James Clear in his book *Atomic Habits – An easy and proven way to build good habits and break bad ones,*[2] describes how Dave Brailsford used this approach. Brailsford suggests that by considering all the abilities required to ride a bicycle, and by working to improve each one incrementally, it may be possible to achieve significant gains when these improvements are marshaled together. Within the context of sports vision, it may therefore be possible to improve many foundational visuo-motor abilities that collectively have meaningful effect on sports performance.

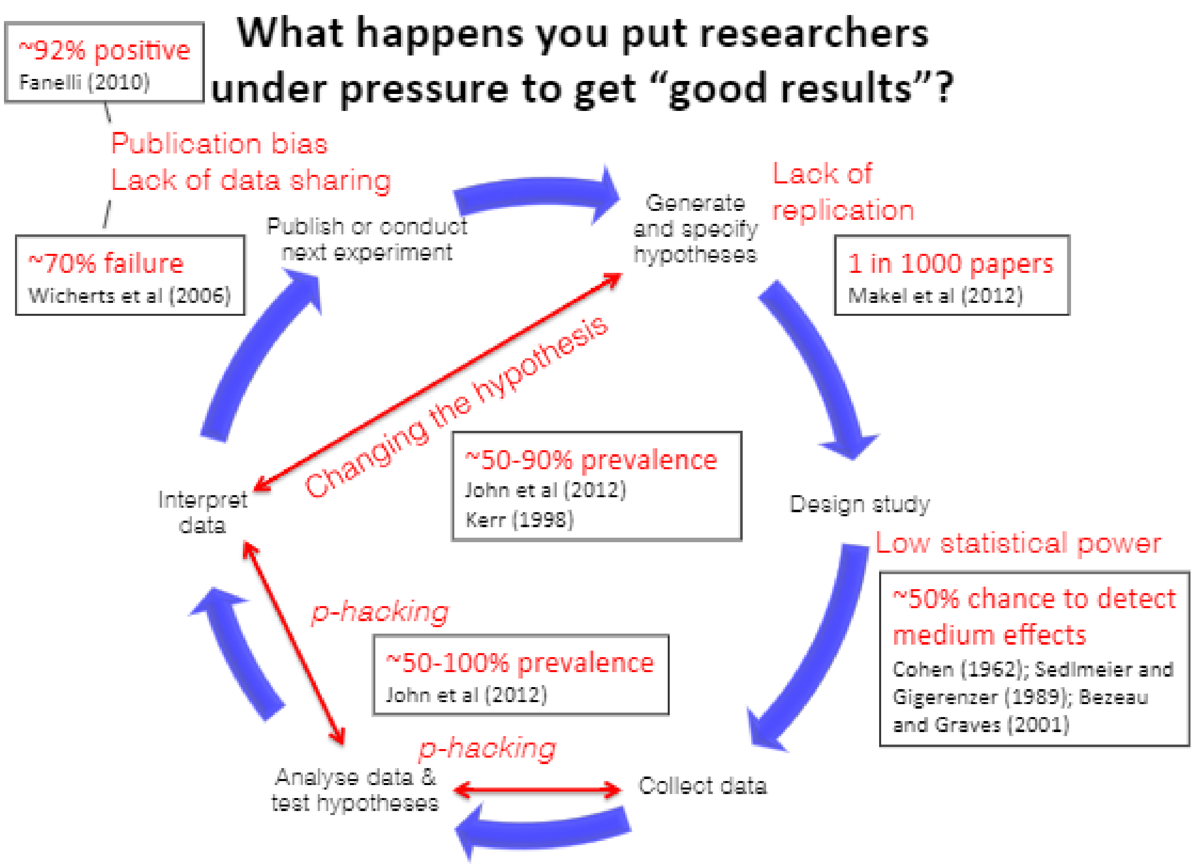
When searching for these foundational visual skills and when evaluating them in a scientific and reproducible manner, there are several areas that researchers should be cognizant of to avoid error and incorrect results. In addition to those described in the manuscript; additional sources of bias include;

a) Retrospective Cost or the "Sunken Cost fallacy": This issue concerns the continuation of testing into an area that has already shown no relationship to sports performance as a result of the time (and money) already invested. Within the realm of sports vision, where time is limited, continuation of effort on unsuccessful approaches can be particularly harmful as it may exhaust the time and faith of the athlete who is looking to improve their performance.

b) The Law of Small Numbers: Also known as the "gambler's fallacy", is the incorrect belief that small samples will resemble the population from which they are drawn. The ratio of occurrence, however, is only useful when considering large datasets, smaller datasets do not follow the same level of predictability. This serves to illustrate the importance of properly powered studies and sufficient sample sizes required to insure a true result.

c) P-Hacking and "HARKing": P-Hacking refers to the misuse of data analysis to find patterns that can be presented as statistically significant, thereby increasing the risk of false positives, but also increasing the likelihood of achieving publication. This problem is enabled by authors adjusting or changing their hypothesis to fit findings where statistically significant (e.g., p-value less than 0.05) results are present, a phenomenon referred to as HARKing, or Hypothesizing After the Results are Known. Both of these violations of the scientific method can be prevented through pre-registration of studies that clearly articulate, and make public, the planned hypotheses and analyses.

Together, these issues have created substantial challenges for the scientific literature at large, including specialties that constitute sports vision. As noted by Chris Chambers and illustrated in ***Appendix Figure A*2**, below, these issues are part of a larger cycle of conduct that contaminates the scientific process. This cycle is further exacerbated by publishing pressures for novel findings above negative results or replications of previous findings, both of which contribute value to the literature but are not prioritized as much by authors, reviewers, editors, and journals.



Appendix Figure A2. *Illustration of cycle of publishing conduct that is detrimental to scientific process*

Fortunately, there is a way to address these concerns and promote a valid and reliable sports vision literature. By applying Open Science approaches, discussed below, many of these issues can be mitigated. Finally, Michael Lewis presents a valuable depiction of the work of Nobel laureates, Daniel Kahneman and Amos Tversky in his book *The Undoing Project*,[A3] that describes sources of bias, errors in thinking and ways to avoid them that may be useful reading for editors, reviewers, and authors of scientific works.

2. A potential solution: Open Science

Many of the issues noted above and in the main manuscript can be improved upon by adopting Open Science principles. This approach creates maximal openness and transparency, allowing the best chance for the scientific community to advance based on valid publications and verified data sets and analysis. Specifically, the following Open Science principles can, and should, be applied to the Sports Vision publication process:

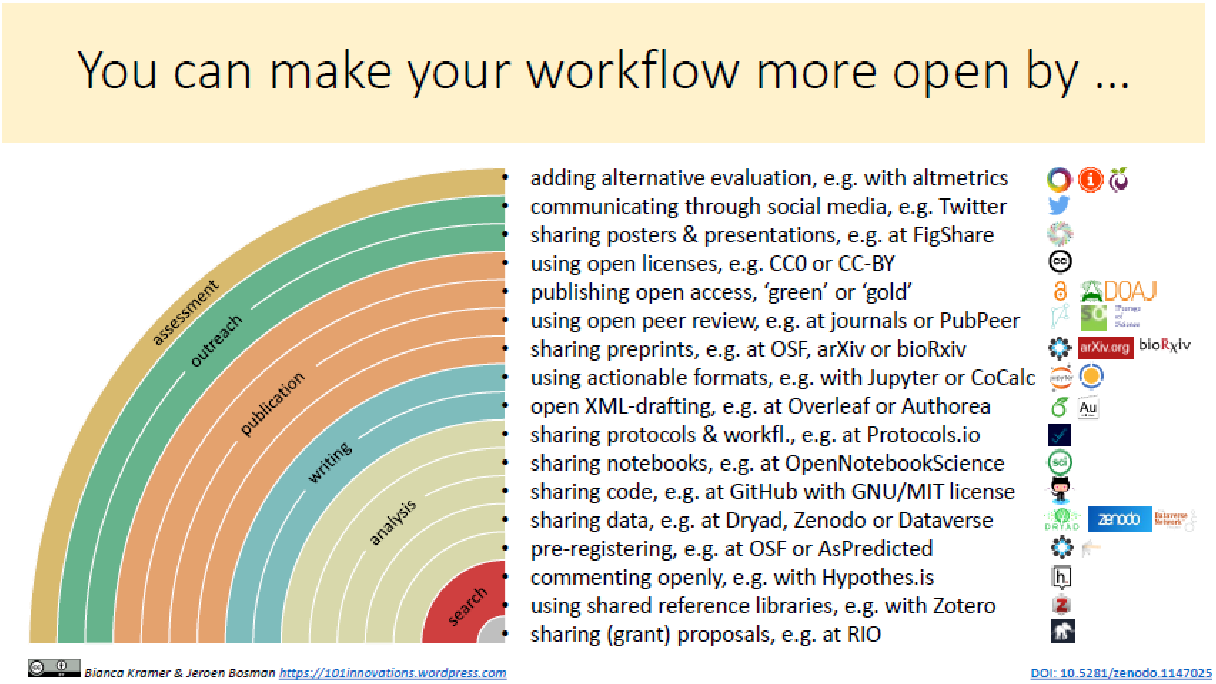
a) Registered Reports are a publishing format that emphasizes the importance of research questions and high-quality methodology by conducting peer review prior to data collection. Protocols are then provisionally accepted for publication if the authors follow through with the registered methodology, thereby rewarding best practices that adhere hypothesis-based, deductive scientific methods. The advantages of this approach for the author is substantial as it guarantees publication prior to performing the study, regardless of positive, negative, or inconclusive results. The advantages to the scientific community though are far greater. This process minimizes many of the issues noted above. Specifically, underpowered studies are minimized, p-hacking and HARKing are reduced, both positive and negative/inconclusive results are published greatly reducing the "funnel" effect, publication bias and selective reporting are also reduced – all of which serve to make the scientific literature more useful and accurate for others in the field. Within the last several years Registered Reports have become commonplace with hundreds of journals, at all levels of impact, now accepting this format

b) Pre-Registration: Similar to registered reports, pre-registration allows for early, public disclosure of the study protocol, analysis plan and endpoints, but does not require journal acceptance for publication. This process, which is commonplace in medical trials, allows the scientific community to review the pre-study hypothesis and statistical method and ensure that they were followed in the final publication. Only a single study in this sports vision literature review utilized pre-registration,[A4] however, this should be the standard in the field going forward.

c) Open Materials and Open Data: The aim of the "Open" approach is to allow others an opportunity to review and verify each step of the scientific process. This allows access to data and the materials of science, promoting transparency and allowing the verification of published results. Additionally, others may be able to take advantage of a dataset for additional, novel analyses that provide new knowledge to the scientific community. It is imperative that proper credit is given if the data of others is used, perhaps even collaborating for even greater insight and benefit.

d) Open Access: A final tenant of the Open Science philosophy is open access to publications, making them accessible to the wider community without cost, as well as others who are not directly involved in scientific research (e.g. journalists, authors, etc.). Open access can be obtained either through submission to journal that provide this service (with or without additional fees to the author) or through pre-print repositories, such as BioRxiv, ArXiv, or MedRxiv that allow for archiving of non-peer-reviewed manuscript in the biological, physical and medical sciences. In addition, federally funded research is now also required to be posted, post-publication, to the National Center for Biotechnology Information allowing access to research funded with federal funds.

To illustrate the value and approach of Open Science, Kramer and Bosman have created a "rainbow of open science" diagram, shown in ***Appendix Figure A*3** below that demonstrates, through each step of the scientific process, how open science can be utilized. Ideally, each author would follow each step in this process, but this is not likely at the current time and thus the rainbow can be viewed as a goal, and a template, authors can use in order to improve their work.



Appendix Figure A3. *Rainbow Open Science diagram.*

In light of the clear benefits of the Open Science approach, we call on journals that publish sports vision topics to adopt an open science framework and to begin accepting, and prioritizing, "Registered Reports", while publishing both positive and negative findings. Additionally, all reviewers should be aware and trained in detecting the issues noted above and include them in their reviews of submissions. As the field of sports vision grows and matures, having a database that reflects good science and accuracy will only help to demonstrate validity to clinicians, athletes, coaches and front office staff regarding the importance of vision in athletic performance.

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