

Three is Better than One – A Call to Consider Triangulation in Sports Science and Sports Medicine

Drei sind besser als eins – ein Aufruf, Triangulation in der Sportwissenschaft und Sportmedizin zu berücksichtigen

Achieving a comprehensive understanding of a particular phenomenon is a key concern of science. However, the inherent complexity of real-world phenomena can rarely be captured by a single theory, study, or assessment method. Therefore, it is necessary to approach a particular phenomenon from different perspectives to make robust and reliable assumptions about it (5, 16). Such an approach, which combines evidence from different sources to address the same phenomenon/research question, is widely referred to as triangulation (7, 25).

What is Triangulation?

The term and approach of triangulation, which is rooted in geometry and has been primarily applied in the field of navigation and land surveying, characterizes the process of forming triangles from typically two known points at the end of a baseline to determine the location of a third, commonly difficult to measure, point with high precision (7, 11, 25). Metaphorically, the fundamental principles of triangulation, particularly the integration of information from different sources, have been transferred to scientific research. Applying this approach offers several key benefits for researchers. Firstly, it allows researchers to gain a more comprehensive understanding of a particular phenomenon (19, 21, 25). Secondly, it can strengthen the credibility of research, which is typically conceptualized as the level of trustworthiness of the study findings (19, 21, 25). Thirdly, it can improve the research's validity, which, depending on the type of validity, refers to how well a concept, instrument, or assessment reflects what it intends to measure or can be generalized to real-world settings (19, 21, 25). Moreover, there is the opinion in the literature that triangulation is a promising approach for addressing contemporary scientific challenges (e.g., 'replication crisis'), which have received growing attention in sports science and sports medicine research in recent years (13).

In this context, it is worth noting that using triangulation provides advantages that go beyond those of strict replication studies (6, 16). While current efforts to improve the reproducibility of research are commendable, a strict replication of a previous study's procedure will neither foster a more comprehensive understanding of a phenomenon nor protect against avoiding the failings of the to-be-replicated research (e.g., bias in study design, methods, and

analysis) (6, 16). In the worst-case scenario, in which the observations of methodologically flawed studies are consistently reproduced, such findings might achieve a status of 'confirmed truth' instead of being rejected (16). This may ultimately harm rather than benefit scientific credibility and progress.

Application in Sports Science and Sports Medicine

Multi-, inter-, and transdisciplinary research work is not uncommon in the broader fields of sports science and sports medicine, including but not limited to multicentre observation and intervention studies. Here, notable examples are an observational study on the prevalence of health-related symptoms of a Coronavirus Disease-19 infection in athletes (28). Other examples are intervention studies investigating the health effects of physical training in individuals with heart failure and preserved ejection fraction (2). Further studies address coronary heart diseases and type 2 diabetes mellitus (15). These projects were conducted by investigator teams with diverse professional backgrounds in sports science, sports medicine, and related disciplines such as cardiology or neurology. Such multi-, inter-, and transdisciplinary research, which can be interpreted as forms of triangulation (e.g., data source and investigator triangulation), often occurs 'naturally' without direct reference to the theoretical concept of triangulation (see examples above).

The systematic use of triangulation has received considerably less attention than replication in current research practice in nearly all scientific fields, including sports science and sports medicine (6, 16). However, integrating information from different key sources, which typically have biases unrelated to each other (11), provides several advantages, especially for enhancing the credibility and validity of research findings (19, 21, 25). Thus, its application is considered promising for advancing knowledge generation, such as improving mechanistic research (1). Based on these advantages, we suggest that triangulation deserves a more systematic and widespread application in the multi-, inter-, and transdisciplinary fields of sports science and sports medicine. To make triangulation more accessible to the reader, this editorial article discusses and defines different types of triangulation (for schematic illustration see figure 1, and for definition see table 1), based on relevant scientific articles (7, 10, 14, 19, 21, 25). Furthermore, it provides examples for selected application scenarios within sports science and sports medicine (see figure 1 and table 1). >

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Table 1

Overview of types of triangulation, and their definition (based on (7, 10, 14, 19, 21, 25)). In case more than one form of triangulation is used to investigate a single phenomenon/research question in a study, this is referred to as multiple triangulation (7, 10, 25). Examples of the application of triangulation in selected subdisciplines of sports science and sports medicine (Example 1 - Association between cardiorespiratory fitness and cognitive performance, and Example 2 – Association of exercise prescription, training load, and biomechanics) are provided.

| TYPE OF TRIANGULATION | DEFINITION AND EXAMPLES |
|--|--|
| Data source triangulation | <p>Definition: ...refers to collecting and using data from multiple sources, but with the same assessment method, focusing on matters such as time (e.g., assessment of the same phenomenon at different times), space (e.g., assessment of the same phenomenon in different laboratories), and persons (e.g., assessment of the same phenomenon in different populations) (7, 10, 14, 19, 21, 25).</p> <p>Example 1: A study investigating cardiorespiratory fitness and cognitive performance is conducted in different laboratories/institutions (e.g., across several countries) using the same study procedures and equipment (i.e., same manufacturer and version). If comparable findings were reported across laboratories, this would strengthen the credibility and validity. If conflicting findings are reported from participating laboratories, this would point towards the influence of specific moderators (e.g., intercultural differences).</p> <p>Example 2: In biomechanics, data source triangulation is used to determine the precise position and movement of body segments by analyzing data from multiple cameras or sensors placed at different body locations and angles. For example, motion capture systems use triangulation to reconstruct 3D joint trajectories during walking or athletic performance. In addition, inertial measurement units (IMUs) and force plates are used to implement further kinematic and kinetic data sources.</p> |
| Investigator triangulation | <p>Definition: ...refers to involving different researchers with complementary expertise in investigating a particular phenomenon (e.g., in study planning, data collection, and interpretation) to minimize individual bias (7, 10, 14, 19, 21, 25).</p> <p>Example 1: To study the associations between cardiorespiratory fitness and cognitive performance through an interdisciplinary lens, researchers from different disciplines provide complementary expertise (e.g., an exercise physiologist concerning the graded exercise test used to determine cardiorespiratory fitness, a psychologist concerning the cognitive assessment used to gauge cognitive performance, and a neuroscientist concerning the application of neuroimaging techniques to record neural activation during cognitive testing). The group of researchers collaboratively designs the study and interprets their findings, while leveraging their unique skills for data assessment and analysis related to their area of expertise and the study's aim.</p> <p>Example 2: In a translational study investigating muscle recovery after injury, a sports physician, a molecular biologist, and a data scientist collaboratively analyse and interpret biomarker profiles, imaging data (e.g., obtained via magnetic resonance imaging), and performance metrics. By applying investigator triangulation, the team ensures that clinical insights, cellular mechanisms, and statistical patterns are integrated to develop more effective, individualized rehabilitation protocols and return-to-play decision-support approaches.</p> |
| Theory triangulation | <p>Definition: ...refers to the act of considering different theories to inform decisions related to study design and implementation, or when interpreting the data (7, 10, 14, 19, 21, 25).</p> <p>Example 1: Different theories (e.g., cardiorespiratory fitness hypothesis, which mainly focuses on the idea that a higher cardiovascular fitness is predictive of better brain health, or cerebrovascular reserve hypothesis, predicting that the benefits of higher cardiorespiratory fitness for cognition are mediated by vascular mechanisms (27)) are used to guide decisions related to study design, data collection, and interpretation.</p> <p>Example 2: Theoretical concepts that focus on the relevance of patients' joints or muscle-tendons' biomechanical parameters, e.g., for successful endurance training, need to be triangulated by theories that cover psychological aspects like self-confidence, motivation, and resilience, and greatly influence 'cognitive fatigue'. Study designs and exercise prescription should therefore combine physical and psychological concepts. Otherwise, relevant factors that affect training outcomes might be missed.</p> |
| Methodological triangulation | <p>Definition: ...refers to using different research methods from a single (e.g., within-methods; ≥ two methods from the same paradigm) or multiple paradigms (e.g., between-methods; ≥ two methods from different paradigms; that can be further differentiated into simultaneously [i.e., at the same time] or sequentially [i.e., after each other, as one method may inform the application of the other]) to collect data (7, 10, 14, 19, 21, 25).</p> <p>Example 1: Different neuroimaging modalities (e.g., electroencephalography to measure neuroelectric changes and functional near-infrared spectroscopy to measure hemodynamic changes) are used to obtain complementary information on cardiorespiratory fitness-related neural activation during a standardized cognitive test (12).</p> <p>Example 2: Different objective measures of external load (e.g., speed), as well as objective (e.g., heart rate) and subjective measures (e.g., rating of perceived exertion) of internal load are used to obtain complementary information about the training load and the exercise stimulus applied (4).</p> |
| Analysis and interpretation triangulation | <p>Definition: ...refers to the application of multiple (statistical) approaches to analyse and interpret the same dataset (7, 10, 25).</p> <p>Example 1: Frequentist and Bayesian statistical approaches (e.g., multilevel modelling, such as hierarchical Bayesian continuous-time dynamic modelling, which has been used in other application scenarios in the field of exercise-cognition research (22)) are applied to study the between- and within-participant associations between cardiorespiratory fitness level, including its modulation via physical exercise, and cognitive performance (see (9) for an example of how Frequentist and Bayesian statistics have been used as complementary approaches for causal inference on the effects of acute endurance exercise on cognitive performance).</p> <p>Example 2: Contextual data of psychometric measures and short-scales (8), as well as training diary information, are implemented for moderator analysis and interpretation of objective biomarkers (e.g., heart rate variability) within monitoring trend analysis (3).</p> |

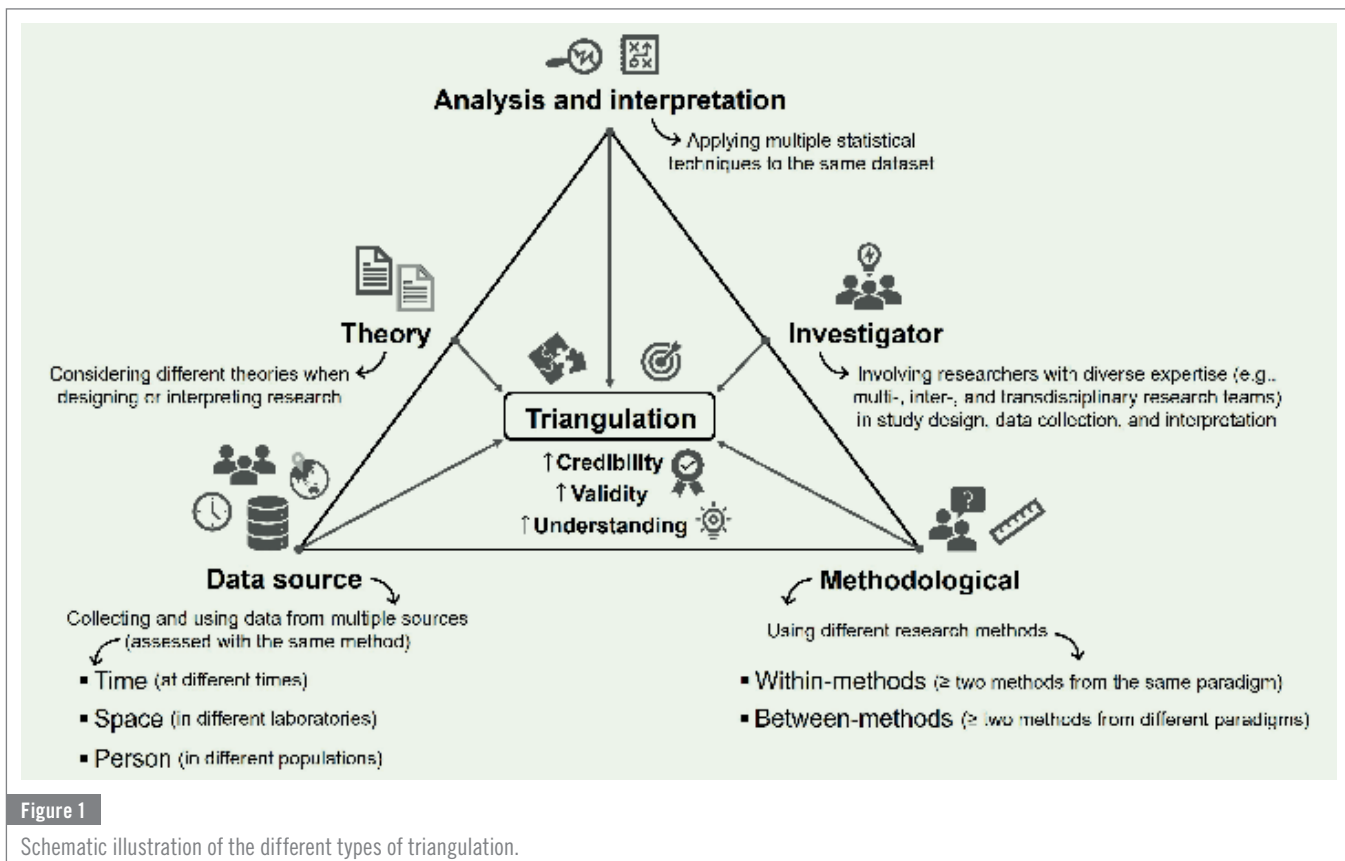


Figure 1

Schematic illustration of the different types of triangulation.

Limitations and Future Remarks

Despite triangulation providing various advantages, this approach has some limitations that need to be considered. Typically, triangulation can be more resource-consuming (e.g., due to the use of additional assessment methods), adds complexity to research (e.g., from dealing with a higher amount of data, or from requiring a relatively high level of coordination/communication between investigators and staff members with complementary expertise to enable a successful interdisciplinary and interprofessional work), and does not protect from inconclusive findings (e.g., in case observations from different sources are conflicting) (7, 19, 25). Although such inconclusive findings can be challenging to interpret and may not allow for firm conclusions, such inconclusiveness can be an important impetus for further research to elucidate the role of specific sources of bias or moderators causing nonconvergent findings (17).

The explicit application of the triangulation approach in sports science and sports medicine research is rare, although there are noteworthy exceptions (23, 26). To foster a more frequent use of triangulation in future research practice in sports science and sports medicine, progress in theoretical direction, including but not limited to the development of best-practice guidelines for designing, conducting, and reporting findings of triangulation studies in this research field, as well as conceptual re-framing of relevant terms, might be required. For example, 'between-method triangulation' is traditionally interpreted as the combination of quantitative and qualitative methods (7, 10, 14). As an alternative, less narrow approach, yet not established, one may consider interpreting the term 'between-method triangulation' more intuitively and inclusively as the application of different qualitative and/or quantitative methods (e.g., functional near-infrared spectroscopy and electroencephalography to assess neural activation via changes in cortical hemodynamic and event-related potentials). In this context, the term 'with-

in-method triangulation' may be reserved to characterize the usage of different outcomes of the same method to operationalize a particular phenomenon (e.g., event-related potentials and spontaneous activity to assess neural activation). In addition to a conceptual re-framing of terms related to triangulation, the use of artificial intelligence (AI), which has gained popularity in the fields of sports science and sports medicine in recent years (18, 20, 24), can provide several advantages for triangulation studies. In particular, applying AI technology has huge potential to advance research practice, for example, by saving resources through automation in various applications (e.g., data analysis). However, when using AI technology, challenges, such as ethical and legal concerns related to data privacy and security, or other issues, including the transparency and reliability of data sources and selection of AI models, should be carefully considered (18, 20, 24). Given this context, future efforts are needed to explore how artificial intelligence can be effectively used as a tool to support triangulation (e.g., in data collection, handling, and analysis).

Finally, to support a systematic and more widespread application of information-rich, yet resource-consuming triangulation studies in sports science and sports medicine, which are likely to generate more robust, credible, and comprehensive evidence, different key stakeholders (e.g., funding agencies) may need to value such efforts to a greater extent (e.g., by providing appropriate funding opportunities) (16).

Conclusions

Triangulation, when appropriately used, is a promising approach to gain a more comprehensive understanding and tackle challenges (e.g., credibility and validity) relevant to sports science and sports medicine research and practice. Thus, this editorial advocates for a more systematic and widespread application of triangulation in this research field, often dealing with highly complex real-world phenomena. ■

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