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On Sports Biomechanics

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Abstract

Sports biomechanics is a highly formalized and captivating discipline within sports science. Despite employing a wide array of methods, it reveals a significant lack of a comprehensive epistemological and methodological foundation, relying primarily on implicit borrowings from its foundational sciences, such as mathematics and physics. This paper seeks to outline the essential components of such an epistemological framework and address key issues arising from its application. The discussion begins by situating sports biomechanics within its broader theoretical context and proceeds to propose a structural framework aimed at bridging the divide between biomechanical theory and practical application. The conclusion advocates for a more holistic and integrated approach to biomechanics, emphasizing its potential to unify diverse methodological perspectives.

Keywords: Epistemology, models, theory, structure, technique

Introduction

As Latour and Woolgar (1986) highlighted in their seminal work Laboratory Life, even in the most renowned, Nobel-Prize-winning laboratories, numerous scientific “facts” are often socially constructed. What begins as hypotheses, opinions, or speculative ideas can, through repeated discussion, gradually transform into “hard facts,” often without explicit acknowledgment of the transition.

Viewed through this lens, this paper examines the *methodology* of biomechanical modelling in sports. Specifically, it aims to integrate biomechanics research into a broader theoretical framework (Papageorgiou & Lekkas, 2020, 2018). While terms such as “biomechanics of tennis strokes” are widely used in contemporary discourse, fully developed models of this kind remain conspicuously absent in the field of tennis. An initial attempt to address this gap was made in 2016 (Papageorgiou, 2016). This study builds on that foundation, addressing a critical void in sports science that has led to significant confusion among both researchers and practitioners: the absence of a coherent epistemological framework.

This work seeks to clarify key epistemological concepts, including *method* and *methodology*, structure, axiom, theory, model, truth, reality, verification, logic, and statistics. Furthermore, it presents the rationale for the structure and design of such models, offering a comprehensive overview—a bird’s-eye view—of their theoretical underpinnings. Finally, it bridges biomechanics and technique in both theoretical perspective and practice.

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Basic epistemological background for coaches and researchers

In previous studies, we have sought to lay the theoretical groundwork necessary to understand where science has faltered and why. Several papers have been published to advance this endeavor, and this brief discussion reflects the insights gained from those efforts (Papageorgiou & Lekkas, 2014, 2019; Papageorgiou & Lekkas, 2020). My general approach is not *historiographical* but *theoretical*—specifically, *epistemological* in nature. Our team benefits from a unique strength: it is founded upon the work of the distinguished mathematician D.E. Lekkas, who has developed an entire modern mathematical discipline on his own, the theory of music (Lekkas, 1994).

The concept of "theory" itself is rooted in the Greek term *θεωρία* (*theōrēa*), which refers to the abstract interpretation of an axiom. Abstraction, in this sense, involves the elimination of specific content in favor of increased generality. For instance, the term "mammal" is more abstract than the term "human". Axioms serve as the foundational postulates within an axiomatic (or theoretical) system, and they are inherently abstract. This absolute level of abstraction ensures that certain concepts, such as the speed of light (in Einstein's theory of relativity), *cannot* be treated as axioms. Axioms, along with their *theoretical derivatives*—such as *theory* and *models*—are evaluated on the basis of their consistency, theoretical productivity, and elegance. Ultimately, theory is intrinsically tied to their axioms, serving as their logical extensions.

Regrettably, Latin scholars failed to coin a term equivalent to the symmetrical Greek term *theōrēsē* (*θεώρηση*), which means "perspective" (maybe, again, for political reasons, since perspectives where "dangerous" in big empires). As a result, the word "theory" in English carries an ambiguous dual meaning, referring both to a *universal abstract archetype* and a *personal point of view*. This confusion aligns with another problematic decision by Latin scholars who, despite translating Greek grammatical terms word-for-word, chose to name the basic Latin grammatical mode *indicative mood* (*modus indicativus*). This designation is opposite to the Greek worldview represented by its equivalent mood and represents a significant conceptual regression with political undertones. English lacks an equivalent term for the Greek grammatical mood, but creating one would be relatively straightforward. A precise translation of the Greek term *enclisis horistikē* would be "definitive mood". In Greek, when describing the world, one *defines* or *conceives* it. Conversely, people speaking languages employing an indicative mood merely *indicate* or *perceive* the world, ignoring the issue of sensory deception.

It is essential to remember that the very origins of *epistēmē* (the Greek, but semantically different, term for "science"), theory, and mathematics lie in addressing the problem of the "fraud of the senses". This problem, being ultimately unsolvable (hence not *actually* a problem), remains a persistent perceived obstacle that scientists in western sciences think they need to solve.

Inevitably, the regression to earlier conceptualizations of the world, exemplified by the basic linguistic mode of the indicative mood, has rendered the foundational distinction between *truth* (*veritas*, *alētheia*) and *reality* (*pragmatikotēta*) inapplicable. In science, unfortunately, there exists no distinguishing between "truth" and "reality". Reality pertains to things themselves (*Dinge an sich*, as Kant described), which are inherently inaccessible to us. Truth, by contrast, pertains solely to abstract theory.

Theory cannot be verified in the real world because verification concerns truth, not reality. What we can do is employ the axiomatic method, along with dual theoretical tools—analysis-synthesis and abstraction-structure—to construct theoretical systems in abstraction. Only afterward can we selectively relate portions of these theoretical systems to the real world through processes of interpretation and application. This selected portion of the theory, adapted to suit specific needs, provides a practical interface with reality.

Should we attempt to describe reality in terms of theory, the field of *theoretics* comes into play. However, in the realm of *epistēmē*, theoretics remain tangential to theory itself—they neither prove nor disprove it but merely serve practical purposes, acting as a form of support or crutch for our understanding of how the world works. Regarding "truth" in every-day situations, or even in laboratory settings, if the goal is to achieve a truthful representation of reality, both Latin and Greek offer complementary terminologies: *verdict* (from Latin, meaning "to speak truthfully in public") and *etymegorēa* (Greek, with the same meaning).

Models, in contrast, are not merely personal perspectives. It is crucial to recognize that there are two primary categories of models: empirical models (world→theory) and surveillant models (theory→world). The third category, theoretical models, pertains to purely mathematical constructs (theory→theory) and lies outside the scope of this discussion. While empirical and surveillant models serve distinct purposes, it is imperative to maintain clarity regarding their original context and avoid conflating them. For instance, an empirical model represents what exists in the world, whereas a surveillant model represents what should exist ideally; yet, oftentimes, someone begins by using an empirical model and later on, they treat it as a surveillant one, which is improper use. This happens despite the fact that all models can be expressed mathematically: this formalization neither validates nor invalidates their applicability to specific real-world scenarios. For example, empirical models, such as "the model of Federer's forehand," are inherently limited in their theoretical rigor and are best understood as purely informational since they have no prescriptive value.

In sports science, axioms are inherently absent because kinesiology, unlike mathematics, is not an abstract discipline. Similarly, tennis cannot possess a proper theory in the strict epistemological sense, but it can only develop theoretics, perspectives, and some models. Surveillant models in tennis, even though they may be used prescriptively, cannot be validated through experimental means, nor can they be derived experimentally; observational data cannot be directly transformed into a proper such model. In field research, the process typically begins with observations, from which selected aspects—filtered through subjective biases—are abstracted into empirical models. The problematic practice arises when these empirical models are later subjected to experiments to claim their status as surveillant models—or even worse, as theory. Experiments, however, cannot create, verify, or falsify theoretical constructs.

Admittedly, this view may seem counterintuitive, given the entrenched reliance of scientists on a different epistemological framework for centuries. However, in logic, theory operates through a *unidirectional flow* from *cause* to *effect*; reversing this flow constitutes a well-known fallacy called *begging the question*. To further clarify, we must now delve into the concept of causality.

Causality in sports science

Cause-effect relationships are always theoretical constructs—they are defined by us and not determined by the phenomenon itself. Even seemingly "trivial" cause-effect relationships are products of human interpretation: Why does the apple fall? Is it due to gravity? Gravitons? The apple's ripeness? The cutting of its stem? Or divine will? It is essential to avoid conflating these interpretations with Humean stimulus-stimulus event sequences, which are merely habitual associations rather than true cause-effect relationships.

Biomechanical models that correspond to e.g. the Fosbury Flop, a tennis serve, or the Kinetic Chain are all abstractions. The application of these models, even across multiple scenarios yielding statistically significant results, can neither confirm nor refute their validity. Testing these models with advanced laboratory equipment merely indicates which interpretation aligns with our current requirements, biases, needs, and resources; it cannot, however, *verify* the model itself. It is worth emphasizing that *statistics* is not a *method of proof*—only *logic* is. Moreover, logic prohibits the evaluation or inference of causes (e.g. models) from observations (e.g. measurements).

Philosophers, from Aristotle onward, have explored methodologies for uncovering the causes of phenomena. Aristotle notably approached causation through the lens of geometry (i.e., mathematics), using it as a reference point for inferential reasoning. During the Middle Ages, figures such as Bacon, Scotus, and Grosseteste made substantial contributions to the systematization of procedures for discovering causality. However, even these scholars overlooked a crucial fact:

phenomena do not inherently reveal their causes. How could they? Causes are always imposed by human interpretation and are never intrinsic to the phenomena themselves.

Consider the example of an athlete who sprains her ankle during a rally. What is the cause?

- Bad shoes,
- bad surface,
- lack of concentration,
- tension from the previous point due to a disagreement with the umpire,
- poor footwork,
- physiological factors (e.g., dehydration, exhaustion, overtraining, hormonal imbalances),
- bad mood (e.g., after a fight with her girlfriend's second mom the previous night),
- a ball boy coughing,
- bad karma,
- good karma (e.g., something bad occurring to prevent something worse).

Any of these reasons could be equally valid, depending on the context and the perspective of the observer. For instance, the athlete's nutritionist might focus on dehydration and exhaustion as the primary causes, while her trainer might attribute the issue to faulty footwork. From the athlete's own perspective, the umpire may be blamed as the most immediate source of frustration, whereas her yoga teacher might interpret the incident as a manifestation of karma.

My approach in this work, as well as more broadly, is neither subjective nor objective—it is theoretical. This third approach is precisely what modern science has lost. Contrary to the entrenched dichotomy between subjective and objective perspectives, the theoretical approach offers a third, alternative framework. Attempting to constrain scientific inquiry within the subjective-objective bipole is one of the most profound misunderstandings of the past centuries.

In Classical Antiquity, *epistēmē* offered a resolution to this bipole. Being subjective was considered overly personal, while being objective was seen as unattainable due to the "fraud of the senses". Importantly, this limitation is not merely a matter of improving measurement techniques; the cause of a phenomenon is never intrinsic to the phenomenon itself—it is a theoretical construct set by us. Consequently, causality, which underpins scientific explanations, is neither subjective (derived from individual sensory experience) nor objective. Instead, it belongs firmly within the realm of the theoretical.

Biomechanics and its models in contemporary research

Contemporary research often fails to distinguish between the concepts outlined above. A particularly notable confusion is the conflation of *methodology* and *method*, as evidenced by the titles of various articles (e.g., Donà et al., 2009). *Methodology* refers to the principles and frameworks underlying the construction of *method*s, whereas *method*s are the specific tools or *technique*s derived from these principles. Furthermore, the emergence of a new *methodology* may constitute a *Paradigm Shift* (Kuhn, 1962) only if it challenges or is incompatible with existing *method*ologies. However, new or alternative measuring *technique*s or *method*s alone do not necessarily qualify as a *Paradigm*.

Biomechanics research broadly follows two primary trends. On one hand, studies aim to present simple, general principles and practical guidelines (e.g., Ae, 2020; Blackwell & Cole, 1994; Fleisig et al., 2003). On the other hand, some research delves into more intricate mathematical analyses of movements (e.g., Hafer & Boyer, 2020; Santuz et al., 2020). The principles and guidelines from the first category are frequently rooted in fundamental physical themes, such as Newton's Laws, kinetic energy, and momentum. However, they may also extend to physiological concepts, including range of motion (ROM) and electromyography.

While these approaches serve distinct purposes, their lack of integration highlights a critical gap in the field. For example, deterministic models often fail to account for the variability inherent in real-world movement patterns, limiting their generalizability (Chow & Knudson, 2011). Similarly, the reliance on principles rooted in classical mechanics does not adequately address the complexity of non-linear systems often observed in sports contexts. A more interdisciplinary approach, synthesizing general principles with advanced modelling techniques, could provide a pathway toward a unified paradigm in biomechanics.

On the mathematical side, there is a pluralism of *biomechanical models*: *analysis*, *geometry*, *trigonometry*, *calculus*, and *linear algebra*, among others (Niederer, 2010; Vallatta, 1992). However, the mathematical representation of a phenomenon does not inherently “prove” its validity as a model—let alone render such representations “prescriptive” for future actions. This raises a fundamental question: how can anyone assert that while all models in biomechanics are *descriptive*, they are also implicitly “objective”, *prescriptive*, and suitable for inductive generalizations? The answer often invoked is *statistics*. Yet, statistics, invaluable in indicating *tendencies*, cannot serve as a proving method; logic can (Papageorgiou, 2020a).

This overreliance on quasi-mathematical expressions—a methodological issue sometimes described by us as *quasi-mathematicity*—has become a pervasive issue in science. It often lends unwarranted importance to findings merely because they are expressed in equations. As the Latin proverb suggests, *quidquid latine dictum sit altum videtur* (what is said in Latin seems profound). Philosophically, this tendency has been characterized as *bullshiting* (Frankfurt, 1986), underscoring the superficiality of such practices.

In this context, deterministic models offer a promising alternative (Chow & Knudson, 2011). These models break down a goal into its constituent components, allowing for multi-level analysis. For instance, in 100-meter sprint analysis, the goal (time) can be deconstructed into speed and distance at a first level, and further into stride length, stride rate, stride time, and velocity at take-off at subsequent levels. Importantly, all levels in such models should be mechanically interconnected. However, a significant limitation arises when the analytical method is not applied from the outset, leading to potential subjectivism (Papageorgiou & Lekkas, 2018).

Finally, biomechanics incorporates various visualization models, ranging from 2D to 3D representations of movement. These can include artistic or graphically designed models. The methodology underlying the creation of these illustrations is critical: Were they derived from player data (via statistics)? Were they shaped by the designer’s experiential knowledge? Or were they created as artistic interpretations of movement? While quantitative mathematical models and qualitative imaging models may differ in their outputs, they are methodologically similar. The key distinction lies in whether the model was conceived in abstraction, as dictated by the method of theory.

The method of theory relies on two paired methods: *analysis-synthesis* and *abstraction-structure* (Papageorgiou & Lekkas, 2018). Analysis involves breaking an entity into segments, while synthesis recombines these segments into either the original or a novel entity (resynthesis). Abstraction refers to placing (including) the entity within a broader superset, and structure identifies subsets within some superset. For example, in analysis, the [athlete] might be deconstructed into *tissues*, *bones* and *nerves*, while abstraction might situate the athlete within the broader category of *performers*, or even that of *humans*, *mammals* and so on, as abstraction continues. A significant methodological risk arises when these methods are conflated—such as reducing *talent* (an abstract-structural component) to analytical-synthetical elements, like the type of *muscle fibres* an athlete possesses.

Structural analysis of technical form

In a holistic framework such as the Distal Method, technique occupies a dual role: it is both part of a broader, unifying paradigm and an object of analytical dissection. Synthesizing this duality, the Distal Method posits that technique should align with unifying principles while also being flexible enough to describe specific movements or shots. This approach ensures that practitioners maintain a bird’s-eye view to foster general expertise, avoiding the overly granular biomechanical analysis that would demand distinct methods for every shot.

The framework integrates several key components:

1. **Sense:** Refers to sensory inputs received from receptors, such as proprioception. Examples include sensations of pushing or pulling, forming the basis of bodily awareness.
2. **Feeling:** The conscious interpretation of sensory stimuli. Often developed during early life, this process requires training to convert sensory input

into actionable understanding.

3. **Emotion:** The psychological imprint of feelings. For instance, a soft hug can evoke happiness in one context or fear in another (from a stranger, in the dark!), depending on the situation and psychological associations.

4. **Biomechanics:** The theoretical abstraction of body mechanics, integrating physics, geometry, and physiology. It serves as the foundation for analyzing movement.

5. **Technical form:** The translation of abstract biomechanics to a concrete movement formation (*domēma*). Technical form refers to distinct movements, skills or shots. Technical form may also be described as *applied biomechanics* or *simplified tactics*.

6. **Technical style:** With time and structured practice, technical *form* evolves into an individualized technical *style*, influenced by personal kinesiological traits, preferences, and psychological patterns. Here, even our neurotic patterns are expressed (enter psychotherapy). Technical style is also the synthesis of the previous components (feeling, emotion, biomechanics and form—synthesis is always necessary after analysis).

7. **Movement synthesis / structure:** Both are movement sequences. Movement sequences that have no further aim are called *syntheses* (“compositions”; e.g. a a blocked drill/*scales in music*). Movement patterns that have an aim related to a specific goal are called movement structures (e.g. agrression-attacking/études in music). Applied technical form is movement synthesis and simplified tactics is movement structure.

8. **Tactical form:** Sequences of movements with an aim regarding the outcome of the whole rally (a point). Tactical form represents the practical execution of tactical planning in a specific situation. May also be viewed as applied structure or simplified strategy.

9. **Tactical style:** Tactical style represents the individual’s long-term, personalized adaptation and refinement of *tactical forms*, emerging over years of deliberate practice. Again, it is a synthesis of the former components.

Note: While *forms* are taught, *styles* are the long-term (*distal*) adaptations of forms and occur spontaneously at some later stage of evolution (which may be called *maturation stage*). “Spontaneously” does not mean tedious preparation isn’t necessary.

10. **Tactical planning:** Tactical planning is the abstract, preparatory phase where actions are designed to achieve a desired outcome. It provides the blueprint (*domikē*) for what needs to happen but remains independent of execution.

11. **Strategy:** Strategy is the overarching combination of tactical planning and execution, encompassing multiple tactics to achieve broader objectives.

12. **Life purpose & Vision:** Life purpose constitutes the culmination of strategies across a career or series of matches, reflecting a proper vision.

Note: Many different *technical* form combinations can express a specific *tactical* form, and many different *tactical* form combinations may contribute to a specific *strategy*. Similarly, multiple strategies may collectively define a *life purpose*. *Proper vision* is a comprehensive explanatory framework that guides *intention*, enhances *discernment* (a virtue), and possesses *transformative power*. Importantly, strategy cannot be inferred

	Level I	Level II	Level III	Level IV
Fundamentals	Sense	Biomechanics	Synthesis/ structure	Tactical planning
Maturation stage	Feeling	Technical form	Tactical form	Strategy
Maturity stage	Emotion	Technical style	Tactical style	Life purpose / Vision

Table 1. A proposed, multilevel structural analysis of the components of performer evolution within the framework of the Distal Method.

from a partial knowledge of the tactics employed, nor can tactics be deduced solely from a partial knowledge of the technical forms utilized. Likewise, life purpose and vision cannot be *uniquely* discerned from a fragmented understanding of the strategies involved.

In Table 1, the different components of the framework are outlined. The fundamentals are indispensable prerequisites before advancing to the maturation stage. Later on, during the maturity stage, the individual's full potential should be realized, provided that an appropriate training method has been employed. At this point, world-class performance becomes an achievable outcome.

The interconnections among these 12 components provide fertile ground for further exploration; however, this discussion will center on biomechanics and *technical form*—referred to hereafter as "*technique*." The critical question for biomechanics and *technique* is: how do we transition from the fundamentals to the maturation stage? This question applies not only to biomechanics and *technique* but to all four levels of development.

The key to this progression lies in the integration of sense and feeling as foundational elements (and through emotion, we transition from *technical form* to *technical style*). This connection is so vital that it may represent the primary mechanism enabling effective distance learning in the context of skill acquisition (Papageorgiou, 2020b). Importantly, this relationship is not confined to remote education; it is equally relevant to any learning context involving the teaching of technique. This foundational relationship between sense, feeling, and emotion (and of other components) is not only central to the teaching of technique but also aligns with broader theoretical frameworks that emphasize the integration of abstract principles with practical applications, such as the Distal Method.

The Distal Method distinguishes itself from other holistic approaches in sports science through its emphasis on theoretical coherence and the integration of abstract principles with practical applications. For instance, Newell's constraints model focuses on the interaction among task, individual, and environmental constraints, illustrating how these factors dynamically shape motor skill acquisition (Newell, 1986). Similarly, Bernstein's stages of learning describe the progression of motor skill development, highlighting transitions from freezing degrees of freedom to freeing and ultimately exploiting them to achieve mastery (Bernstein, 1967).

While both frameworks provide valuable insights into motor learning, they emphasize adaptability and responsiveness to specific contexts rather than a comprehensive, unified approach, aimed at world class motor expertise. The Distal Method, in addition to what already exists, constructs an overarching framework that links sensory inputs, biomechanics, and strategic *planning*, creating a seamless pathway for skill acquisition and mastery, i.e. motor expertise. Its foundation in dual processes—*analysis-synthesis* and *abstraction-structure*—ensures that *technical forms* and *styles* are adaptable across diverse levels of expertise and environmental conditions.

Moreover, the Distal Method addresses the hierarchical progression from basic sensory inputs (e.g., proprioception) to the development of high-level strategies, situating these within the context of long-term (*distal*) cognitive-motor and psycho-ethical athlete development. By offering both a theoretical and practical scaffolding via specific tools (presented in other papers), it extends beyond dynamic adaptability to provide a unifying lens for understanding the evolution of performance across a career. This holistic integration aligns with calls for multidimensional approaches in sports science, as emphasized in recent studies (Oktavia et al., 2020; Meyers, 2006). Other aspects of the Distal Method, not directly relevant to our discussion here, provide even more tools for the other aspects of world class motor expertise.

Shaping technique

Technical form is the observable manifestation of movement, allowing us to deduce, for example, that a performer belongs to a particular school or tradition. In contrast, *technical style* is the personal imprint on movement, making it instantly recognizable as belonging to a specific individual. For instance, one might observe a movement and declare, "I recognize from that alone—it's *that* performer!"

The development of technical forms arises from various, sometimes unexpected, factors:

- Disabilities or Movement Limitations: Historical examples include the overweight Kung Fu master who adapted his art to suit his physical condition. This adapted style became widely adopted by students, regardless of whether they shared the same limitations.
- Imitation: As seen in martial arts such as Eagle Claw or Mantis Kung Fu, where practitioners emulate insect movements, imitation also heavily influences sports like tennis. Players mimic the techniques of top athletes, assuming these forms to represent an optimal standard. However, this approach often perpetuates a counter-theoretical cycle of blind replication rather than innovation.
- Tactical Reasons: Deceptive techniques, such as those found in “drunken-style boxing”, exemplify the use of tactical adjustments to influence the opponent’s perception and strategy.
- Political and Religious Constraints: Cultural and religious norms can restrict the permissible forms of movement, shaping technical forms to align with societal values.
- Biomechanics: The pursuit of optimizing movement mechanics to achieve maximum efficiency and effectiveness underpins much of sports science. This focus ensures that technical forms reflect the principles of physics and physiology.

Several studies explore the intersection of biomechanics, technique, and the factors shaping technical forms. For example, Chow and Knudson (2011) discuss the role of deterministic models in understanding movement mechanics, highlighting the interplay between biomechanical efficiency and personal adaptations. Similarly, Newell (1986) emphasizes the role of *constraints*—environmental, individual, and task-based—in shaping motor skill acquisition, demonstrating how external factors influence the development of technical forms.

Bernstein’s 1967 work on coordination further illustrates how movement patterns evolve through iterative (repeated) learning and adaptation, underscoring the influence of intrinsic (e.g., physical limitations) and extrinsic (e.g., cultural norms) factors. Research in motor learning has also addressed imitation, revealing its dual role as a facilitator of skill acquisition and a potential barrier to innovation when overemphasized (Fitts & Posner, 1967).

Structure:
The Bridge from Biomechanics to Technique

The most effective bridge from biomechanics to technique is structure. The term “structure” derives from the Latin translation of the Greek word *domē* (*δομή*). Unfortunately, the Latin translation pruned the rich semantic possibilities of the Greek term. In English, only two terms stemming from Lat. *structura* are available—*structure* and *structuring*—and, consequently, only two ideas are conceivable this way. By contrast, the inherent quadrupolar structure of the Greek language extends further, encompassing four symmetric terms:

1. *Domē*: The abstract *archetype* or conceptual blueprint.
2. *Domikē*: The *methodology* or the *systematic process*, or *the steps* of creation and construction.
3. *Domēsis*: The actual act or process of creating or constructing.
4. *Domēma*: The final, tangible product or result of the process.

These terms can be directly correlated with concepts in biomechanics and *technique* as follows:

1. *Domē* (Biomechanics): The abstract idea of a movement, conceptualized and sketched as a blueprint—on paper or mentally.
2. *Domikē* (Teaching methodology): The pedagogical framework that translates abstract ideas into practice programs, skill segmentation, practice distribution, and instructional principles.
3. *Domēsis* (Training): The actual process of training and performing the movements.
4. *Domēma* (Technical form / Style): The product of training, manifesting as a technical form or personalized style.

This framework offers the much-sought bridge between theory and practice, emphasizing a seamless progression from abstract ideas to practical implementation. Notably, the Distal Method aligns with these principles, offering tools to address all four stages within this epistemological framework (Papageorgiou, 2019).

Progressing from *domē* to *domikē*, then to *domēsis*, and finally to *domēma* is not an arbitrary sequence. It reflects a theoretical necessity in Classical Epistemology. Any deviation from this elegant order risks producing a distorted and incomplete understanding of the relationship between biomechanics and technique.

As a reminder, for a theoretical framework to be valid within this epistemological tradition, it must meet four key criteria:

1. Consistency: Logical coherence across all stages.
2. Completeness: Covering the fuller possible theoretical scope.
3. Theoretical Productivity: Offering new insights or applications.
4. Elegance: Combining simplicity with clarity; also other aesthetic criteria peculiar to each domain.

For applied models, two additional criteria ensure practical effectiveness:

- Predictive Power: The ability to forecast outcomes accurately.
- Accommodative Strength: Flexibility to incorporate diverse scenarios.

On the Role of Measurements

While measuring methods are a crucial component of sports biomechanics methodology, they do not play a prescriptive role in the context of theory development. Even when measurements involve elite athletes or successful trials, they remain descriptive rather than prescriptive. According to Classical Epistemology, such prescriptive models must be created prior to measurements, as theory (not always respected by science) considers the world to be the end, not the starting point, of intellectual inquiry.

If verification of theory through observations were possible, it would contradict the foundational principles of *epistēmē*. Such verification would render the achievements of Classical Epistemology obsolete, reducing scientific inquiry to a form of "witchcraft" reliant on arbitrary experimental outcomes—a tendency that we argue persists in the overemphasis on experimental methods today.

Extensions and Implications

The structured progression from *domē* to *domēma* is more than a theoretical framework; it is an epistemological bridge that connects abstract ideas with the tangible realities of human movement. This model, rooted in the principles of Classical Epistemology, not only elucidates the relationship between biomechanics and technique but also opens pathways to broader applications and reflections on the nature of learning, adaptation, and performance.

A Return to Epistemological Rigor in Sports Science

The epistemological framework utilized calls for a reorientation of sports science toward its theoretical foundations. By emphasizing all parts of the method of theory, and conceptual clarity before experimentation, it resists the contemporary over-reliance on statistical validation. This approach safeguards against the reduction of biomechanics to mere data collection, reaffirming its role as a discipline that combines principally abstract reasoning with empirical insight being the end result. In this way, it challenges the prevailing tendencies that prioritize experimental outputs over theoretical coherence, urging the field to reclaim its intellectual depth.

Harmonizing with Holistic Frameworks

The quadrupolar structures employed integrate seamlessly with established holistic models such as Newell's constraints model, which emphasizes the interplay of task, individual, and environmental factors, and Bernstein's coordination framework, which explores movement variability and learning through stages. Together, these frameworks underscore the iterative and adaptive nature of skill acquisition. The *domē* framework adds a distinct dimension: an insistence on epistemological progression that transitions from abstract *archetype*s to personalized *technical styles*. This synthesis bridges the gap between theoretical elegance and practical adaptability, offering a unified perspective on motor learning.

A Vision for Coaching and Education

Coaches and educators can leverage the "*domē* framework" to design training programs that respect the natural progression of learning. By first emphasizing *domē* (abstract archetypes) and *domikē* (methodology, in our case), they can ensure that athletes grasp the conceptual underpinnings of technique before moving to *domēsis* (practice) and *domēma* (performance). This progression nurtures not only technical skill but also a deeper understanding of whole process of athletic development, enabling athletes to personalize their style while maintaining biomechanical efficiency. This vision holds promise for the future of education in sports, particularly in the realm of distance learning, where abstract conceptualization and clear methodologies are paramount.

Challenging the Empirical Orthodoxy

The model critiques the dominance of empirical orthodoxy in sports science, where measurements and experiments often overshadow theoretical inquiry. The insistence that theory precedes observation serves as a corrective to this imbalance, reminding researchers that the world is not the starting point of theoretical work but its culmination. This perspective resonates with the core principles of *epistēmē*, reasserting the primacy of thought in the pursuit of knowledge.

Expanding Beyond Sports

The methodology employed here is not peculiar to sports science—let alone to tennis or any other specific sport. Its structured approach to translating abstract concepts into practical applications makes it equally valuable in fields such as education, engineering, and the performing arts. For instance, it can guide *curriculum* design, product development, or artistic creation by emphasizing progression from foundational principles to mastery. The universal applicability of this framework underscores its theoretical robustness and interdisciplinary relevance.

Toward a Philosophy of Movement

At its core, the framework employed here invites a broader philosophical reflection on the nature of movement itself. By situating movement within a structured epistemological framework, it challenges us to consider not just how we move, but why. It connects the physical act of movement to its intellectual and emotional dimensions, suggesting that technique is as much about personal expression and cultural context as it is about efficiency and mechanics. This vision aligns with emerging perspectives in sports science that view movement as a form of communication and identity, rather than merely a biomechanical process.

The future

A unified, prescriptive *methodology* for biomechanics must eventually emerge, serving as a foundation for interdisciplinary exploration and integration. Such a *methodology* would systematically account for all possible combinations implied in Table 1, enabling nuanced understanding and application across diverse contexts. These combinations could include, but are not limited to:

- *Technical Biomechanics*
- *Biomechanical Technique*
- *Sensory Biomechanics*
- *Biomechanical Sense*
- *Emotional Biomechanics*
- *Biomechanical Emotions*
- *Tactical Biomechanics*
- *Biomechanical Tactics*

This interdisciplinary vision acknowledges that biomechanics is not an isolated domain but one that inherently intersects with sensory perception, emotional intelligence, and tactical decision-making. It calls for a synthesis of these elements into a cohesive framework that reflects the multidimensional nature of human movement.

Bioinformatics will undoubtedly play an increasingly prominent role in advancing sports biomechanics and related fields. By leveraging bioinformatics, expert systems, and Artificial Intelligence, researchers can develop predictive models with unprecedented precision. However, these tools should not be mistaken for solutions in themselves. As powerful as they are, they remain secondary to the methodology outlined here; a methodology grounded in theoretical abstraction and epistemological rigor will ensure that such technologies serve as enablers rather than determinants of progress.

Ultimately, the future of biomechanics lies in its ability to integrate technical, sensory, emotional, and tactical dimensions into a cohesive and prescriptive science. Achieving this vision will require both methodological innovation and a steadfast commitment to theoretical abstraction and epistemological rigor, ensuring that human creativity remains central to advancing the field.

Conclusion

This paper has explored the critical intersections between biomechanics, theoretical frameworks, and practical applications within sports science. By addressing gaps in epistemological gaps in sports science, by distinguishing among the various types of models, and highlighting the central role of theory, rather than reality, in science, it offers a pathway for advancing both the discipline and its application. The proposed integration of sensory, emotional, and tactical dimensions with technical principles through a structured methodology not only strengthens the theoretical foundations of biomechanics but also ensures its adaptability across diverse contexts. Ultimately, this work advocates for a reorientation of sports science toward a unified, prescriptive framework that prioritizes intellectual rigor and human creativity. The future of biomechanics, as envisioned here, is not merely about refining movements but about elevating the understanding and execution of human potential through theory-driven practice, i.e. *surveillance*.

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