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Editorial

From Cycling 1.0 and 2.0 to Cycling 3.0: The Evolution of a Sport through Science, Ethics, and Artificial Intelligence

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Abstract

This editorial presents a comprehensive account of cycling's historical and conceptual evolution from the traditional and empirically-based *Cycling 1.0*, through the collaborative, ethical and evidence-driven *Cycling 2.0* (Zabala & Atkinson, 2012), to a proposed *Cycling 3.0* era shaped by artificial intelligence (AI). Drawing on original sources, publications, and later empirical studies, it argues that the sport's ethical and scientific progression should remain grounded in transparency, collaboration, and athlete education. The *Cycling 3.0* paradigm can amplify the benefits of 2.0, provided that its algorithms, data systems, and governance frameworks can respect the humanistic and ethical foundations that rescued cycling from its 1.0 crises.

Keywords

Cycling 2.0; Cycling 3.0; Athlete 2.0; Ethics; AI; Sport Science; Anti-Doping; Governance

1 Introduction

The history of competitive cycling can be divided into epistemic eras defined by distinct relationships between empirical knowledge, science, and ethics. *Cycling 1.0* represents an empirically oriented yet ethically fragile system; *Cycling 2.0* -conceptualized originally by Zabala & Atkinson (2012) and developed in several articles and media outlets (Zabala, 2012a; Zabala, 2012b; Arribas, 2013; Morente-Sánchez & Zabala, 2013; Morente-Sánchez & Zabala, 2014; Morente-Sánchez et al., 2013; Zabala, 2013; Maestre, 2015; Zabala et al. 2016; Zabala, 2017; Zabala, 2021; Zabala, 2024)- marks a paradigmatic shift toward evidence-based, multidisciplinary, and ethically guided practice; and *Cycling 3.0* signals the beginning of an AI-enhanced, data-intensive, and governance-dependent epoch. These transitions describe a sport learning to integrate technology without surrendering its ethical compass.

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2 Cycling 1.0: Tradition, Intuition, and Ethical Fragility

Cycling 1.0 was characterized by hierarchy, empiricism, and secrecy. Training relied on tacit coaching wisdom, and the absence of structured scientific collaboration allowed practices that blurred medical, ethical, and professional boundaries. The Festina (1998) and Armstrong-era scandals epitomized this vulnerability: doping networks flourished in opaque environments with minimal scientific oversight (Fincoeur et al., 2020). The collapse of *Cycling 1.0* was not merely a moral crisis but an epistemological one -trust in the sport's capacity for self-regulation evaporated. These events catalysed the demand for a transparent, science-anchored framework that could rebuild credibility and athlete welfare.

3 Cycling 2.0: The Scientific and Ethical Revolution

Although David Brailsford (British cycling) is considered the maximum exponent of the scientific approach and "marginal gains" applied to cycling performance (Clear, 2018) and the contribution to "modern cycling" was proved highly beneficial (highlighting the role of well-prepared science-based coaches or other technicians), the humanizing and ethical principles were not expressly considered. And just before the guilty plea of Lance Armstrong -that was commented in press by Zabala (2012b) as a necessary "Tsunami" to start the real healing of cycling and a new promising cycling era-, Zabala & Atkinson (2012) introduced *Cycling 2.0* concept as "a collaborative challenge" grounded in three principles: (a) scientific measurement, (b) multidisciplinary cooperation, and (c) ethical responsibility. It was both a methodology and a philosophy. Performance decisions were now informed by reproducible data -power output, HRV, lactate thresholds, biomechanics- and interpreted through coordinated expertise (coaches, scientists, physicians, nutritionists). The athlete, once a passive subject, became an informed collaborator and, necessarily, the main character.

A central component of 2.0 was *education*. The "athlete-scientist" model encouraged riders to understand their own data, enhancing compliance, motivation, and accountability (Zabala, 2013), so that it should be included among the principles of training the "pedagogic principle" (Rønnestad and Zabala, 2017). This pedagogical shift democratized expertise and fostered trust between riders and staff; and as Horcajo and Zabala (2017) also suggested, it is necessary to promote a culture within a cycling team in accordance with the ethical principles and values, at the time information does not lead to the situation called "paralysis by analysis", created by too much and not well directed information. In this sense, "athletes' individual data threshold" (Zabala, 2022; Zabala, 2023) should be taken into account for a meaningful learning process.

Ethical transformation accompanied this scientific restructuring. Research by Morente-Sánchez et al. (2013) showed Spanish female cyclists and triathletes increasingly rejecting doping as "cheating." Maestre Rodríguez (2015) extended this analysis to "millennial" athletes socialized within the 2.0 framework, identifying a new ethical generation that perceives fair play, scientific literacy, and anti-doping compliance as inseparable from professional identity. This generational evidence substantiates that *cycling 2.0* was not a technological revolution alone, it was an ethical one. The integrity of 2.0 depends on professional accreditation and role boundaries. Zabala (2021) warned of a "Troy horse" inside elite teams: unqualified or ethically compromised individuals occupying performance or science roles without

credentials. Such intrusiveness risks re-introducing 1.0 pathologies -hidden agendas, pseudoscience, and moral erosion- into the new paradigm. Continuous professionalization and transparent governance therefore remain essential.

In this sport science and cycling coaching context, the Cycling 2.0 label has sometimes been used superficially, without explaining its full meaning or citing its educational and ethical foundations. Some recent works (e.g., Sitko, 2025) have adopted the term more as a label than a philosophy, omitting references to the original widely cited works. Such behaviour detaches the term from its moral and empirical content, reducing it merely to a marketing brand. Defending the integrity of the Cycling 2.0 concept should be an ethical obligation of those professionals involved in cycling science and the development of this sport in the healthiest manner. As the humanist philosopher George Santayana wrote more than a hundred years ago, "those who cannot remember the past are condemned to repeat it" (Santayana, 1905-1906). This appears to be a real danger if newer generations are not well-grounded in the history and facts of the discipline, making it difficult to respect the past to better build a present and future.

4 Cycling 3.0: Artificial Intelligence as Amplifier and Ethical Test

Just one specific reference has been reported online as the concept "cycling 3.0" but in relation to the globalization of road cycling competitions around the world (Vega, 2019), and a couple of indirect mentions like the one promoting a new indoor cycling method called "indoor cycling 3.0" (Barbado, 2025), or the German National program to promote cycling in Germany until 2030 called "National Cycling plan 3.0" (federal Ministry of Transport, federal government of Germany, 2025). So, given these non-related antecedents and focused on cycling as a sport and social manifestation, we propose our Cycling 3.0 philosophy and concept; and following our proposal, firstly we must say that cycling 3.0 is not replacing cycling 2.0, it magnifies its potential while exposing its weaknesses. Artificial intelligence introduces predictive analytics, machine learning, and digital-twin modelling to sport science. If it is properly implemented, AI can integrate multi-sensor data, enhance safety through early-warning algorithms, support anti-doping intelligence, and expand athlete education via adaptive learning interfaces. However, without ethical governance, AI could reverse 2.0's gains. Algorithmic opacity, data commodification, and unequal access create new vulnerabilities. Cycling 3.0 must therefore be *ethics-by-design*: transparent models, auditable data pipelines, and human-in-the-loop decision rights (Zabala, 2021).

To extend the *cycling 2.0* values into the AI age, the following operational steps are essential, as a governance roadmap for the *cycling 3.0* era:

1. Standardise measurement and metadata (Zabala, 2013).
2. Establish federated research consortia for privacy-preserving data sharing.
3. Maintain ethical accreditation to prevent the so-called "Troy horse" (Zabala, 2021).
4. Promote AI literacy for coaches and athletes.
5. Ensure open audit trails and transparent algorithmic validation.

As we enter this third evolutionary stage, cycling stands at an unprecedented crossroads between human wisdom and machine intelligence. Artificial intelligence will not replace the coach, the scientist, or the athlete, but it will augment them. The success of *Cycling 3.0* will depend not on how quickly we

adopt new algorithms, but on how wisely we integrate them into a culture of shared knowledge, respect, transparency and responsibility. If the spirit of *Cycling 2.0* - collaboration, education, and ethics- remains our compass, then AI can become the next ally in a journey that should continue to be profoundly human. The challenge is not merely to predict performance, but to protect meaning. In that, the science of cycling will find its next revolution, and perhaps its greatest harmony.

5 Comparative Summary

In the following table, the three cycling eras are compared in terms of different dimensions like the epistemic base, athlete role, ethics and governance, technology, key risks and cultural drive:

Table 1. Comparison of the three cycling eras according to their attributes.

Dimension	Cycling 1.0	Cycling 2.0	Cycling 3.0
Epistemic base	Tacit, experiential, hierarchical	Empirical, multidisciplinary, evidence-based (Zabala & Atkinson 2012)	AI-augmented, predictive, federated models
Athlete role	Passive subject	Educated collaborator and main character, "Athlete 2.0"	Data co-producer, human-in-loop decision-maker
Ethics & governance	Fragmented	Anti-doping culture, accreditation, transparency (Morente-Sánchez et al. 2013; Maestre, 2015)	Algorithmic accountability, privacy, fairness
Technology	Minimal, later wrong directed or underused technology (e.g. powermeters)	Power meters, HRV, cloud analytics etc (Zabala 2013), understanding technology	Machine learning, digital twins, anomaly detection
Key risks	Doping, secrecy	Intrusiveness ("Troy horse") (Zabala 2021), paralysis by analysis, overinformation	Algorithmic bias, data misuse
Cultural driver	Authority	Collaboration and clean-sport ethics (Zabala & Atkinson 2012)	Ethics-by-design and digital literacy
Start-end	Since first road cycling competitions until Armstrong's guilty plea (Fincoeur et al., 2020)	Since Armstrong's guilty plea to the irruption of AI	Since the irruption of AI until…

6 Conclusions

In conclusion, the evolution from *Cycling 1.0* to *cycling 2.0* and now toward *cycling 3.0* is not just a technological continuum but a moral and epistemic reconstruction. *Cycling 2.0* rebuilds the sport's legitimacy through science, collaboration, ethics and education. *Cycling 3.0* can expand this progress only if AI systems inherit -not replace- those ethical foundations. Principles like transparency, pedagogy, and athlete agency must remain non-negotiable. The future of cycling as a sport (where sport sciences play a key role) depends less on computational power than on moral coherence: the algorithm must serve the athlete, not the other way around. As Zabala (2017) highlighted regarding *Cycling 2.0*, a balance must be found between the naive and the negative perspectives, seeking a clear pathway to a fairer and more humanized sport in which education and prevention are key.

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