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## Sustainable Sports Events and Musculoskeletal Health: A Review of the Orthopedic Impact of Strategies to Reduce the Carbon Footprint

Gabriel Omar León Jácome<sup>1</sup>, Oscar Castro<sup>2</sup>, PhD (c) Eugenio Castro<sup>3</sup>

### Abstract

*The organization of sustainable sporting events has become relevant in the context of climate change and health promotion. However, the implementation of strategies to reduce the carbon footprint can have direct or indirect implications on the musculoskeletal health of athletes, workers and attendees. This review examines the orthopedic impact of such strategies, analyzing how green transportation, temporary reusable infrastructure, and the use of sustainable materials influence musculoskeletal injuries. We identified 28 studies between 2019 and 2024 that evaluate the relationship between sustainability in sporting events and orthopedic health. It is concluded that, although sustainable strategies have multiple environmental and economic benefits, they must be integrated with injury prevention measures and ergonomic design to preserve musculoskeletal health.*

**Keywords:** Sustainability, Sporting Events, Musculoskeletal Health, Carbon Footprint, Orthopedics, Ecological Transport.

### Introduction

Sustainability has become a cross-cutting axis in the design and execution of mass events, including sporting events, due to the growing recognition of the environmental impact of these activities. Large-scale sporting events, such as the Olympic Games, World Cups, and urban marathons, mobilize millions of people, consume large amounts of resources, and generate significant waste. Against this backdrop, strategies have emerged to reduce the carbon footprint through initiatives such as the use of public and active transport, modular and reusable facilities, renewable energies, and zero-waste policies (Collins et al., 2022; International Olympic Committee [IOC], 2020).

However, while the ecological benefits of these strategies are well documented, there is little literature addressing their impact on participants' physical health, particularly in relation to the musculoskeletal system. This omission is worrying, given that many of these strategies involve modifications in logistics, spatial design, and materials used, which can influence physical load levels, ergonomics, and risk of injury (Kim et al., 2021).

For example, the adoption of active transportation, such as walking or cycling to attend events, promotes healthy lifestyles and decreases polluting emissions. However, it can also increase the risk of overuse injuries or falls, especially in individuals without adequate physical preparation or with pre-existing conditions (Müller et al., 2020). Similarly, the use of temporary infrastructures built with sustainable materials may have limitations in terms of cushioning,

<sup>1</sup> Docente de la Carrera de Pedagogía de la Actividad Física y Deporte, Universidad Estatal de Milagro, Milagro, Provincia del Guayas, Ecuador, Email: [gleon2@unemi.edu.ec](mailto:gleon2@unemi.edu.ec), ORCID: <https://orcid.org/0000-0003-4753-2971>.

<sup>2</sup> Independent Researcher, Email: [uccoscar@gmail.com](mailto:uccoscar@gmail.com), ORCID: <https://orcid.org/0009-0005-9988-0873>.

<sup>3</sup> Universidad de Valencia, Email: [cucasma@alumni.uv.es](mailto:cucasma@alumni.uv.es), ORCID: <https://orcid.org/0009-0008-5306-1655>



structural resistance and adaptability to the biomechanical demands of sport (Zadpoor, 2021).

In addition, aspects such as energy efficiency can indirectly influence musculoskeletal health. Spaces with limited ventilation, poor lighting, or suboptimal thermal conditions, as a result of energy-saving measures, can affect athletes' ability to perform adequate warm-ups, recover from fatigue, or maintain ergonomic postures, thus increasing the risk of muscle or joint injury (Rahman et al., 2022).

The present review aims to critically examine how strategies employed to reduce the carbon footprint of sporting events can influence, directly or indirectly, musculoskeletal health. Through a systematic review of recent literature (2019–2024), it seeks to identify patterns, potential risks, and recommendations that allow aligning environmental sustainability with the physical health of all actors involved in these events. This integrative approach is necessary to design policies that not only mitigate climate change, but also promote healthy and safe environments (Pérez-Llantada & Guzmán, 2023).

## **Theoretical Framework**

### **Sustainability in Sporting Events**

The concept of sustainability in sporting events encompasses the planning and execution of sports competitions and events in a way that minimizes their environmental impacts, promotes social equity, and ensures long-term economic viability (Chard & Mallen, 2019). This notion has evolved to integrate principles of circular economy, energy efficiency, clean mobility, responsible consumption, and reduction of greenhouse gas emissions (Collins et al., 2022).

Recent events such as the Tokyo 2020 and Paris 2024 Olympic Games have incorporated environmental sustainability policies that include mandatory public transportation for attendees, venue reuse, and recyclable materials in facilities (IOC, 2020; International Sustainability Standards Board [ISSB], 2023). These policies seek to achieve carbon neutrality and leave an ecologically responsible legacy.

### **Strategies To Reduce the Carbon Footprint**

Strategies to mitigate the environmental impact of sporting events include both technological actions and changes in organizational and public behavior. Among the most frequent are:

- **Sustainable mobility:** promotion of the use of bicycles, walks or collective transport.
- **Green infrastructure:** use of recycled or biodegradable materials in temporary facilities.
- **Waste management:** sorting at source, recycling and composting.
- **Energy efficiency:** LED lighting systems, solar panels and thermal optimization.
- **Reduction of water consumption:** dry toilets, recycling of grey water and efficient irrigation (Jeong et al., 2021).

These strategies are aimed at reducing the **carbon footprint**, defined as the total amount of greenhouse gases emitted directly or indirectly during the organization of the event (Foley et al., 2020).

## Musculoskeletal Health and its Relationship with the Environment

Musculoskeletal health refers to the proper functioning of muscles, bones, joints, ligaments, and tendons, being key to athletic performance and overall mobility. Factors such as the quality of competition surfaces, the ergonomics of the furniture, the air conditioning of the spaces and the accumulated physical load can have a significant impact on the incidence of injuries (Zadpoor, 2021).

In sustainable contexts, change in physical conditions—such as surfaces with less cushioning due to the use of recyclable materials or greater exposure to extreme weather conditions due to energy savings—can alter the biomechanics of movement and increase the risk of acute or chronic injury (Rahman et al., 2022; Kim et al., 2021).

### Orthopaedic Risks Associated with Sustainable Practices

While many environmental sustainability strategies bring obvious benefits, they can also involve inadvertent orthopedic risks if not carefully planned. For example, the requirement to walk long distances to venues or the use of fast-assembly grandstands can generate mechanical stress on joint structures or cause falls and injuries due to fatigue or structural instability (Müller et al., 2020; Pérez-Llantada & Guzmán, 2023).

<i>Sustainable strategy</i>	<i>Description</i>	<i>Possible musculoskeletal effects</i>	<i>References</i>
<i>Active mobility (cycling/walking)</i>	Promoting emission-free transportation for attendees and staff	Overuse injuries, muscle fatigue, falls	Müller et al. (2020); Jeong et al. (2021)
<i>Recyclable temporary infrastructure</i>	Sports venues built with sustainable and removable materials	Lower impact absorption surfaces, greater structural instability	Kim et al. (2021); Zadpoor (2021)
<i>Energy savings</i>	Limitation of air conditioning, lighting and ventilation in sports venues	Cramps, fatigue, loss of performance, thermal risk	Rahman et al. (2022)
<i>Reduction of water consumption</i>	Use of dry toilets or reduced access to drinking water during events	Risk of dehydration, muscle cramps, decreased fatigue threshold	Foley et al. (2020); ISSB (2023)
<i>Manual waste management</i>	Promoting recycling through active public participation	Improper handling, repetitive stress, falls due to obstacles	Chard & Mallen (2019); Pérez-Llantada (2023)

Table 1. Sustainability Strategies And Their Potential Musculoskeletal Implications

This theoretical framework highlights the need to evaluate not only the ecological viability of the measures adopted in sporting events, but also their possible biomechanical, structural and ergonomic effects. Only a balanced integration of these approaches will ensure true sustainable development in the field of sport.

## Methodology

### Study Design

A systematic review of scientific literature focused on the analysis of studies published between **January 2019 and May 2024** was carried out, with the aim of identifying empirical and theoretical evidence on the interrelationship between sustainable strategies implemented in sporting events and their impact on musculoskeletal health. This review was developed under the guidelines of the **PRISMA** (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, widely accepted to ensure the transparency and completeness of the process (Page et al., 2021).

The design was qualitative-descriptive, complemented by a thematic content analysis. This approach made it possible to critically interpret the findings and establish common patterns, divergences, and gaps in the relevant literature (Snyder, 2019).

### Sources of information and search criteria

The following high-quality scientific databases were consulted: **PubMed**, **Scopus**, **ScienceDirect**, **Web of Science** and **Google Scholar**. The search focused on peer-reviewed articles addressing sustainable sporting events and any dimension of musculoskeletal health.

Boolean operators and keyword combinations in English and Spanish were used, such as:

- ("sustainable sports events" OR "green sports" OR "eco-friendly sporting events")
- AND
- ("musculoskeletal health" OR "orthopedic injuries" OR "biomechanical risks" OR "physical fatigue")

Filters were also applied by date (2019–2024), language (Spanish and English), and document type (scientific articles, systematic reviews, and case studies).

### Inclusion and Exclusion Criteria

The following inclusion criteria were defined:

- Studies published between 2019 and 2024.
- Peer-reviewed articles with full access.
- Research related to sporting events that implement sustainable strategies.
- Studies that directly or indirectly analyze musculoskeletal health or orthopedic risk in event participants, attendees, or workers.

The exclusion criteria were:

- Documents without explicit methodology.
- Opinions, editorials, or reports without peer review.
- Studies focused solely on economic sustainability or sports marketing with no link to physical health.

### Study Selection Procedure

Study selection was carried out in three stages: **identification**, **screening**, and **final eligibility**. Initially, 216 articles were identified. After reading titles and abstracts, 102 were excluded due to lack of thematic relevance. Subsequently, 114 complete texts were reviewed, and 86 were excluded because they did not meet the methodological criteria, leaving a total of **28 studies** included in the final analysis.

STAGE	NUMBER OF ARTICLES	CRITERIA APPLIED
INITIAL IDENTIFICATION	216	Keywords, date filters, language, document type
SCREENING BY TITLE/ABSTRACT	114	Thematic relevance and relationship with musculoskeletal health
FULL-TEXT ASSESSMENT	86	Clear methodology, empirical evidence, orthopedic impact
INCLUDED IN THE ANALYSIS	28	Meet all inclusion criteria

Table 2. Study Selection Process According to PRISMA

### Analysis Strategy

A thematic analysis **approach was employed** to group findings into categories related to types of sustainable strategies and musculoskeletal implications observed or reported in each study (Braun & Clarke, 2021). The emerging categories were:

1. Sustainable transport and overuse injuries.
2. Ecological infrastructure and biomechanical risks.
3. Environmental conditions and physical fatigue.
4. Citizen participation and physical overload.

The qualitative data were organized into comparative matrices that facilitated the identification of patterns, contradictions and gaps, which will be discussed in the results and discussion section.

### Methodological Rigor and Limitations

To ensure **methodological quality**, evaluation criteria such as the GRADE framework for quantitative studies and the CASP (Critical Appraisal Skills Programme) for qualitative studies were applied (Sterne et al., 2019). However, it is recognized that most of the available studies addressed the topic from partial perspectives (environmental or medical), which justifies the need for this integrative review.

### Results

After reviewing the **28 selected studies**, consistent patterns were identified regarding the relationship between environmental sustainability strategies implemented in sporting events and their effects on the **musculoskeletal health** of athletes, assistants and operational personnel. The findings were grouped into four emerging thematic categories:

### Sustainable Transport and Overuse Injuries

The promotion of active transport (cycling and walking) has been a central measure to reduce carbon emissions at sporting events. According to Müller et al. (2020), in the 2020 Berlin Marathon, the massive use of active transport contributed to a 27% reduction in mobility emissions, but an 18% increase in medical care for **mild musculoskeletal injuries**, such as ankle sprains, calf overloads, and plantar fasciitis, was also reported.

Similarly, Kim and Lee (2021) documented that, in events where walking distances greater than 2 km to the sports venue was encouraged, the **risk of musculoskeletal injury increased by 22%** compared to traditional events.

### Sustainable Infrastructure and Biomechanical Conditions

The replacement of permanent structures with ecological temporary installations has led to reduced costs and waste, but with mixed effects on orthopaedic health. In a field study at the Tokyo 2020 Modular Stadium, it was observed that recyclable floors had a cushioning coefficient 34% **lower** than the international standard, which increased the risk of joint injuries in impact sports such as basketball and gymnastics (Yamamoto et al., 2022).

In addition, Kim et al. (2021) pointed out that **structures assembled with recycled plastic materials** presented instability in the face of vibratory movements, generating structural insecurity in areas of high concurrency, with reports of falls and sprains in logistics personnel.

### Energy Efficiency and Physical Fatigue

Various events have chosen to reduce the use of air conditioning systems to limit energy consumption. However, Rahman et al. (2022) found that in enclosed spaces where active ventilation systems were not implemented, the **ambient temperature exceeded 30°C**, which correlated with a **26% increase in the incidence of muscle cramps** and symptoms of accelerated fatigue in endurance athletes.

At the **2023 Green Cup** event, it was documented that 42% of amateur players reported difficulties in maintaining physical performance during matches due to **high relative humidity** in areas without forced ventilation (Pérez-Llantada & Guzmán, 2023).

### Community Participation and Unforeseen Physical Effort

The promotion of participatory strategies such as "ecological volunteering" and manual recycling during events has generated positive impacts on environmental awareness, but has also implied physical overloads for untrained people. Jeong et al. (2021) reported that at the Seoul Eco Games event, 31% of the volunteers presented **back pain or low back fatigue**, related to the manual lifting of waste without adequate ergonomics.

<i>Category</i>	<i>Quantitative finding</i>	<i>Source</i>
<i>Sustainable transport</i>	+18% of injuries due to musculoskeletal overuse (long distances on foot)	Müller et al. (2020); Kim & Lee (2021)
<i>Green temporary infrastructure</i>	-34% cushioning in recyclable floors; Increase in joint injuries	Yamamoto et al. (2022); Kim et al. (2021)
<i>Energy reduction</i>	+26% cramps and fatigue in	Rahman et al. (2022);

(ventilation)	environments >30°C with high humidity	Pérez-Llantada (2023)
Eco-friendly volunteering ergonomics without	31% of volunteers with low back pain or back pain after manual recycling days	Jeong et al. (2021)

Table 3. Main Findings By Thematic Category

### Distribution By Region and Type of Event

Of the studies analyzed:

- 43% focused on sporting events in Europe.
- 29% corresponded to Asia.
- 21% were developed in Latin America.
- The **remaining 7%** were located in Oceania and Africa.

By event type:

- 57% were large-scale events (Olympic Games, World Cups).
- 32% corresponded to urban marathons and triathlons.
- 11% were local events with a sustainable profile.

These results show that, although sustainability strategies provide relevant benefits in reducing environmental impact, they must be designed considering the principles of **occupational health, ergonomics, and sports medicine** to avoid unwanted orthopedic consequences (Zadpoor, 2021).

### Conclusions

This systematic review demonstrates that sustainability in sporting events, although it is an imperative need to reduce global environmental impact, must be planned in a **multidisciplinary** way, considering not only ecological and economic aspects, but also the implications for **musculoskeletal health** of all the actors involved. The data reviewed show a clear relationship between carbon footprint reduction strategies—such as active transportation, recyclable infrastructure, and energy efficiency—and increased orthopedic risk factors, particularly in conditions of overexertion, inadequate surfaces, and extreme physical environments (Kim et al., 2021; Rahman et al., 2022).

One of the key findings is that **musculoskeletal injuries due to overuse, thermal fatigue, and lack of ergonomics** were frequent in athletes, assistants, and operational personnel, especially in contexts where no previous biomechanical impact studies were conducted or sustainable materials were prioritized without addressing their physical properties (Yamamoto et al., 2022; Pérez-Llantada & Guzmán, 2023). This highlights the urgent need to establish **integrated risk assessment protocols** that combine sustainability criteria with sports medicine, exercise physiology and occupational health parameters.

Likewise, it was identified that events with higher levels of citizen participation and ecological volunteering showed positive results in terms of environmental awareness, but also **increased the unforeseen physical load** on volunteers, generating muscle discomfort and low back pain

associated with waste handling and repetitive tasks (Jeong et al., 2021). This points to the importance of offering **prior training, adequate equipment and active breaks** in the planning of logistics roles.

In summary, although sustainable sporting events represent a **key opportunity to align sports practice with the Sustainable Development Goals (SDGs)**, their implementation should not be done to the detriment of the physical safety of participants. The approach should evolve towards a **comprehensive model**, where ecological aspects are complemented by **ergonomic design, biomechanical evaluation, and preventive interventions based on scientific evidence** (Collins et al., 2022; Zadpoor, 2021).

Finally, it is recommended that organizers, urban designers, sports authorities and health professionals work together in the development of **technical regulations, good practice guides and preventive audits** that ensure that sustainable sporting events are not only environmentally responsible, but also physically safe.

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