PATALONG, Mikołaj, WIĘCKOWSKA, Katarzyna, PUSTUŁA, Paweł, MICHNOWSKA, Wiktoria, KOŁODZIEJ, Przemysław, CZAPLIŃSKI, Mieszko, SZPLIT, Ewa, BILYK, Andrii, BRUSKA, Natalia and CEMAGA, Roman. The Impact of Climate Change on Tennis Performance - a Review of Evidence. Quality in Sport. 2026;50:67928. eISSN 2450-3118.
https://doi.org/10.12775/QS.2026.50.67928
https://apcz.umk.pl/QS/article/view/67928

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 l.p. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 02.01.2026. Revised: 15.01.2026. Accepted: 15.01.2026. Published: 27.01.2026.

The Impact of Climate Change on Tennis Performance - a Review of Evidence

Mikołaj Franciszek Patalong[1], ORCID https://orcid.org/0000-0003-4230-7521

E-mail patalongmikolaj@gmail.com

[1]Individual Medical Practice Mikołaj Patalong, ul. Zabrzańska 26, 41-907 Bytom, Poland

Katarzyna Więckowska[2], ORCID https://orcid.org/0009-0002-4233-1927

E-mail kwieckowskarusek@gmail.com

[2]Individual Medical Practice Katarzyna Więckowska, Deszczowa 18, 40-318 Katowice, Poland

Paweł Pustuła[3], ORCID https://orcid.org/0009-0003-4494-1080

E-mail p.pustula@icloud.com

[3]Family Medicine Centre, Medical University of Gdańsk, ul. Dębinki 7, 80-211 Gdańsk, Poland

Wiktoria Michnowska[4], ORCID https://orcid.org/0009-0003-7161-0105

E-mail wikmic0@gmail.com

[4]University Clinical Centre in Gdańsk, ul. Dębinki 7, 80-952 Gdańsk, Poland

Przemysław Kołodziej[5], ORCID https://orcid.org/0009-0003-5725-2372

E-mail przemyslaw.i.kolodziej@gmail.com

[5]Individual Medical Practice Przemysław Igor Kołodziej, Alojzego Felińskiego 30/9 41-923 Bytom

Mieszko Czapliński[4], ORCID https://orcid.org/0009-0003-8052-4129
E-mail 194058@uck.gda.pl
[4]University Clinical Centre in Gdańsk, ul. Dębinki 7, 80-952 Gdańsk, Poland

Ewa Szplit[6], ORCID https://orcid.org/0009-0001-1464-6027
E-mail e.szplit@gmail.com
[6]Gdańsk Medical University, Marii Skłodowskiej-Curie 3a, 80-210 Gdańsk, Poland

Andrii Bilyk[7], ORCID https://orcid.org/0009-0001-5020-1113
E-mail andrzej.bilyk02@gmail.com
[7]Independent Public Healthcare Facility of the Ministry of the Interior and Administration in Gdańsk, Kartuska 4/6, 80-104 Gdańsk, Poland

Natalia Bruska[4], ORCID https://orcid.org/0009-0008-5749-874X
E-mail bruska.nataliax@gmail.com
[4]University Clinical Centre in Gdańsk, ul. Dębinki 7, 80-952 Gdańsk, Poland

Roman Cemaga[8], ORCID https://orcid.org/0009-0003-8372-2905
E-mail rcemaga@gmail.com
[8]Medical University of Białystok / Uniwersytet Medyczny w Białymstoku, Jana Kilińskiego 1, 15-089 Białystok, Poland

Corresponding Author
Mikołaj Franciszek Patalong, Email patalongmikolaj@gmail.com

Abstract

Background

Climate change is one of the defining challenges of the modern era, with growing evidence of its wide-ranging health implications. Increasing attention has been given to its impact on sport, as climatic conditions significantly influence athletic performance and health. Rising temperatures and changing humidity patterns are expected to disproportionately affect outdoor sports such as tennis, increasing health risks for athletes.

Aim

This study aims to evaluate existing evidence on the impact of climate change on tennis player performance and the functioning of the broader tennis community, providing insights relevant to sports executives, medical professionals and athletes, and supporting the development of adaptation and health-protection strategies.

Material and Methods

A comprehensive literature review was conducted, analysing 42 studies published between 2000 and 2025 and indexed in PubMed, Google Scholar and Scopus.

Results

The evidence demonstrates a clear association between climatic conditions, particularly elevated temperatures, and reduced physiological performance, increased risk of adverse health events and impaired recovery. Climate-related disruptions have also affected tournament scheduling. Adaptation measures, such as infrastructure improvements, revised match protocols and targeted education, are increasingly necessary to protect athlete health and strengthen sector resilience.

Conclusions

Climate change is already impacting the health of athletes and the operational stability of professional tennis. While some adaptation strategies are emerging, more comprehensive action is urgently required to safeguard welfare and ensure long-term sustainability. The global popularity of tennis and the influence of elite athletes could further support advocacy for climate mitigation efforts addressing the root causes of the crisis.

Keywords: tennis, athlete health, climate change, heat stress, sport performance and environmental physiology

AI statement: Artificial intelligence tools have not been used to produce or alter the scientific content of the paper. Publicly available AI-powered websites have been used to identify better wording for certain expressions and sentences to ensure a smooth reading experience, while having no impact on the interpretation of cited evidence.

1. Introduction

Climate change constitutes one of the core civilizational challenges of our time, having been recognised as such by the scientific community and international bodies such as the United Nations, culminating in the adoption of the Paris Agreement in 2015. [1] The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992 and legally binding since 1994, is the official international process that aims to limit the human-derived interference in climate conditions by devising climate adaptation and mitigation strategies and coordinating intergovernmental action to limit anthropogenic greenhouse gas emissions. [1-2] Ten years after the Paris Agreement was reached in 2015, the desired maximum threshold of average global temperature rise of 1.5 degrees Celsius above pre-industrial levels remains under threat, with current scientific estimates suggesting that it has already been passed, with humanity heading towards climate conditions more adverse to life on earth. [3] Health impacts of the climate crisis have been increasingly documented across scientific literature, highlighting direct and indirect threats to physical and mental well-being. [3-5] Health risks associated with changing climate conditions are particularly pronounced in both junior and professional sports, primarily due to the intensity of exertion and the outdoor setting for many sports disciplines. [6] The UNFCCC has striven to engage the sports community in promoting climate action, both in the context of adapting a climate-vulnerable industry in the face of the ongoing crisis, but also utilising the social aspect of sports, and the popularity of athletes, to engage diverse communities on meaningful, universal and timely climate action. The Sports for Climate Action Initiative, founded jointly by the UNFCCC and the International Olympic Committee (IOC), has promoted the objective of limiting the climate impact of the sport industry through emission measurement and reporting instruments, followed up by strategies to mitigate these emissions, while working in parallel to sensitise sports audiences to the issue and promoting reasonable consumption behaviours. [7]

The climate conditions that are currently observed, coupled with projections of the Intergovernmental Panel on Climate Change (IPCC), jointly underpinned by the presently available and growing evidence on the vulnerability of sport to the climate crisis, raise questions as to whether the sports community is adequately prepared to meet the moment, protect the health of athletes and spectators, and ensure that physical activity in professional and leisure contexts remains a tool for improving health, not endangering it. [8-9]

2. Research materials and methods:

2.1. Data collection and analysis

A comprehensive literature review was conducted by utilising Google Scholar, Scopus and PubMed databases. The following keywords were used for the search: tennis, athlete health, climate change, heat stress, sport performance and environmental physiology. The author reviewed articles referring to direct physiological effects, performance outcomes, injury risks, and tournament organisation under changing climate conditions. The author took note of the journals of publication to identify reliable sources, and appropriate measures were taken to check the reliability of citations that provided the relevant information.

3. Results:

3.1. Physiological effects of climate change and related heat in tennis

Exposure to environmental heat is a known factor that puts strain on the human cardiovascular and muscular systems, as well as on the thermoregulation mechanisms of the body. [9] Climate change amplifies the demands put on these regulatory mechanisms. As temperatures during the sports match increase, the body is forced to put more effort into maintaining thermal equilibrium. [10] Tennis is a sport discipline where these effects are particularly strongly pronounced, due to its intermittent high-intensity nature, long match durations, limited time windows for recovery and the predominantly outdoor environments in which competitions are held. [11]

Human thermoregulation is reliant on sustaining the balance between heat generation and heat dissipation. [12] During tennis matches, it is not uncommon for body temperature to reach the levels of 38-39 degrees Celsius. [13] In most situations and contexts, the body temperature will not exceed levels deemed to be threatening to human health. An analysis from 2014 points to missing evidence specific to tennis on the impact of thermal strain on tennis players. [13-14] In the context of climate change, elevated ambient temperatures and altered humidity patterns substantially reduce the efficiency of evaporative cooling. [15] In hot environmental conditions, the cardiovascular system is positioned to seek to meet two objectives: delivering blood to muscles to ensure their proper oxygenation, while ensuring loss of heat to the environment through vasodilatation of cutaneous blood vessels. [16-17] Sustained, uninterrupted physical activity resulting in perspiration, coupled with increased total volume of all vessels, leads to reduced plasma volume, which in turn causes a decrease in cardiac stroke volume. [18] Tennis players may lose 1-2 litres of fluid per hour, and in extreme heat, this loss may exceed the rate at which fluids can feasibly be replaced. [11]

Humidity also plays a crucial role in this process. High humidity restricts the evaporation of sweat, causing its accumulation on the skin without any cooling benefit. [19] The body responds to this by further increasing sweat production, which accelerates dehydration and a further loss of electrolytes, with very little effect on the core body temperature. In extreme conditions, core temperature may exceed 40°C, placing athletes at risk of exertional heat stroke. [20]

Another association with climate change is related to rising levels of air pollutants, including ozone, particulate matter ($PM_{2.5}$ and PM_{10}), and smoke related to wildfires caused by climate change. [21] Poor air quality is linked to decreased pulmonary function, which in turn leads to decreased blood oxygenation, which negatively impacts muscle function and recovery. [22] Athletes with pre-existing pulmonary conditions (e.g. asthma) might be at a particular risk for further vulnerabilities related to poor air quality in indoor and outdoor settings. [23-25]

3.2. Performance outcome effects

Elevated temperatures and humidity have a consistently negative, measurable impact on tennis performance - there is evidence of manifestation of these effects within cognitive, technical, behavioural and psychological domains. Through the combined stress imposed on the thermoregulatory and cardiovascular systems, the athlete progressively loses their capacity to sustain high-intensity physical activity, while simultaneously having their precision and coordination impaired, which impacts optimal execution of a match. [26] Consequently, climate-induced changes in environmental conditions are expected to contribute to measurable declines in performance output, as well as its consistency throughout tennis competitions. [27]

Similarly, heat stress is thought to be closely associated with slower reaction times and reduced vigilance, which results in impaired executive function, understandably essential for high-level tennis games, although some authors downplay or deny this trend. [28-29] Decreased efficiency of decision-making may lead to delayed anticipatory responses, poorer selection of shot targets and decreased situational awareness during matches. Taking into account the complexity of point construction in tennis, deficient acuity is likely to shift the balance between the players, increasing the likelihood of tactical errors and diminishing pre-planned strategies. [30] As mentioned above, this mechanism is still debated. [29]

Thermal load accumulation during a match is seen as another critical mechanism. Hot atmospheric conditions contribute to neuromuscular fatigue, which manifests through reduced muscle power, slower initiation of major and precise movements (diminished fine motor

control). [31] These effects translate into decreased serve velocity, inconsistencies in groundstroke timing, and overall likelihood of errors. [31-32]

Dehydration and cardiovascular strain play central roles in performance reduction. Sustained loss of fluids leads to reduced stroke volume, requiring a compensatory rise in heart rate to maintain adequate cardiac output. [33] Importantly, blood flow in the cerebral area is also affected, although there is no consensus on whether that impacts brain metabolism. [34] Simultaneously, diminished evaporative cooling efficiency in hot and humid environments results in elevated core temperatures, further exacerbating fatigue and impairing both physical and cognitive functioning. These physiological responses form a feedback loop in which rising thermal stress steadily reduces performance capacity as the match progresses. [35]

In terms of behavioural impact, players are likely to adjust their match strategies in response to heat exposure. These adaptations typically include shorter rallies, reduced court coverage, more conservative point construction and a decline in aggressive shot selection. [36] Similar pacing strategies are protective mechanisms that limit continued heat accumulation. Regrettably, they lead to altered competitive dynamics of the match. [31-33]

As climate change continues to intensify temperatures and disrupt traditional weather patterns, these disparities may become more pronounced, underscoring the need for clearer heat policies, improved tournament scheduling and comprehensive adaptation strategies. [37]

3.3. Impact on matches and tournaments

Organisation of sports tournaments can often be disrupted by adverse weather and climate conditions. Heatwaves, high humidity, intense rainfall and sudden extreme weather events contribute to frequent scheduling delays, match suspensions and, in some cases, outright cancellations. [37] These disruptions are particularly evident in outdoor tournaments, where playability and athlete safety are closely tied to climate conditions. [38]

Operational and economic consequences follow directly from these climate-related interruptions. Tournament organisers face increased costs associated with medical staffing, cooling infrastructure, shading systems and adjustments to match scheduling. Spectators are also affected, with elevated heat posing health risks, reducing attendance and creating logistical challenges related to ticketing, transportation and on-site services. Smaller tournaments are disproportionately impacted due to limited financial and infrastructural capacity to implement robust heat-management measures. [37]

3.4. Adaptation and mitigation strategies

The growing impact of climate change on tennis necessitates coordinated adaptation and mitigation efforts aimed at safeguarding athletes' health and ensuring the long-term viability of the sport. Adaptation strategies focus primarily on reducing heat exposure and improving on-site resilience. [39] These include the implementation of evidence-based heat policies, such as the use of wet bulb globe temperature (WBGT) thresholds to guide match suspension or rescheduling, as well as expanded access to cooling interventions - ice towels, mist fans, shaded rest areas and enhanced hydration protocols. [40] Infrastructure upgrades, including covered courts, improved ventilation systems and shaded spectator seating, further strengthen tournament resilience. [41]

Mitigation strategies aim to address the sport's climate footprint by decreasing emissions associated with tournament operations. [42] Initiatives include transitioning facilities to renewable energy sources, optimising transportation logistics for players and staff, and promoting sustainable practices among spectators. The visibility of tennis and its global athlete community offers additional potential for climate advocacy, supporting broader societal engagement on climate action while modelling sustainable behaviours within the sports sector. [42]

4. Discussion:

The findings of this review indicate that climate change poses a substantial and growing threat to tennis, with implications that extend across physiological performance, athlete health, and the operational stability of tournaments. While the physiological effects of thermal strain are well described in the broader sports literature, the available evidence specific to tennis remains comparatively limited. Nevertheless, the reviewed studies collectively highlight a coherent pattern: rising temperatures and altered humidity conditions impair thermoregulatory efficiency, accelerate dehydration, and increase cardiovascular and neuromuscular load during match play. These physiological disruptions translate directly into performance deficits, particularly in domains requiring precision, rapid decision-making and sustained high-intensity movement.

Performance-related outcomes are influenced not only by direct physiological strain but also by cognitive and behavioural responses to heat. Slower reaction times, diminished executive function and reduced vigilance, although subject to some debate, have been reported

under elevated thermal conditions. These impairments are of particular concern in tennis, where rapid anticipatory processing and precise technical execution are central to competitive success. Similarly, behavioural adaptations such as conservative pacing strategies or shortened rallies serve as protective mechanisms but fundamentally alter the nature of match dynamics. These findings suggest that climate-induced environmental stressors may gradually shift the tactical patterns and physical demands traditionally associated with professional tennis.

Climate change also exacerbates health risks for players. Heat-related illnesses, including heat exhaustion and exertional heat stroke, remain rare but medically serious consequences of prolonged play in extreme conditions. Musculoskeletal injuries, driven by dehydration-induced reductions in muscle elasticity and neuromuscular control, are a more frequent concern. Moreover, the intersection of climate change and deteriorating air quality introduces further risks for respiratory function, particularly among athletes with asthma or airway hyper-responsiveness. These health impacts underscore the need for improved monitoring, early warning systems and the incorporation of medical expertise into tournament management.

Beyond individual health and performance, climate change affects the organisational sustainability of tennis events. Increasingly unpredictable weather patterns, including heatwaves, heavy precipitation and severe storms, disrupt scheduling, raise operational costs and reduce spectator safety and comfort. While major tournaments have begun to implement adaptation measures such as retractable roofs, misting zones and more comprehensive heat policies, smaller events remain disproportionately vulnerable due to limited financial and infrastructural resources. This uneven capacity to adapt raises concerns about the long-term accessibility and equity of the global tennis ecosystem.

The evidence base supporting these observations, however, is subject to important limitations. Much of the literature referenced in this review draws from studies on other endurance or outdoor sports, with tennis-specific data often sparse or limited to isolated physiological experiments. The lack of longitudinal research makes it difficult to assess whether repeated exposure to high heat imposes chronic health consequences for junior or professional players. Additionally, while evidence on operational impacts exists for major tournaments, there is a paucity of data regarding how climate instability affects local, developmental and recreational tennis events, where protective measures and financial buffers are minimal.

These gaps create a compelling case for further research. Long-term cohort studies are needed to clarify chronic heat-related risks for tennis players. More refined modelling of performance degradation under realistic match conditions would support evidence-based heat policies. Finally, comprehensive analyses of economic and organisational impacts across different tiers of competition would assist governing bodies in allocating resources and designing targeted adaptation strategies.

Taken together, the findings reviewed here indicate that tennis is highly sensitive to the advancing climate crisis. Addressing this vulnerability will require coordinated action by tournament organisers, sporting institutions, medical professionals and the players themselves. Without such efforts, both the safety of athletes and the operational continuity of the sport risk becoming increasingly compromised in a warming world.

Limitations of the study include mainly the fact that there is very little discipline-specific evidence available for tennis, with a large portion of past research using generalised statements relating to all outdoor sports disciplines. Evidence related to the impact on the organisation of sports events focuses on major tournaments, the disruption of which incurs high one-time expenses, while evidence on the perturbation caused to small-scale, non-professional events is lacking. Longitudinal data on chronic effects of repeated heat exposure in junior and professional tennis players remain equally scarce.

Future research should focus on:

- Long-term cohort monitoring of both junior and professional tennis players;
- Improving modelling of tennis performance degradation related to heat;
- Improving understanding of heat-related risk to health among professional athletes;
- Assessing economic and organisational impacts on tournaments worldwide.

5. Conclusions

The findings of this review demonstrate that climate change already exerts a measurable and multifaceted impact on tennis, influencing both athlete performance and the broader functioning of the sport. Rising temperatures, worsening humidity profiles and declining air quality interact with the physiological demands of tennis to impair cognitive sharpness, technical execution and overall match consistency. These effects are accompanied by

heightened risks of acute thermal illness, musculoskeletal injury, and cardiovascular or respiratory strain, all of which pose direct threats to athlete health and safety.

Climate change also challenges the operational stability of tennis events. Increasingly frequent heatwaves, extreme weather events and environmental instability disrupt match schedules, impose significant economic burdens on organisers and reduce the comfort and safety of spectators. Smaller tournaments, which constitute a substantial portion of the global tennis ecosystem, appear particularly vulnerable due to limited infrastructural capacity and fewer resources dedicated to heat mitigation.

Although several adaptation measures, such as heat policies guided by WBGT values, enhanced cooling provision, modified match scheduling and infrastructure improvements, are beginning to emerge, they remain unevenly implemented. To safeguard athletes and ensure the long-term viability of the sport, a more consistent and evidence-informed approach is required across all levels of competition. In parallel, tennis institutions should embrace mitigation strategies that address the environmental footprint of tournaments, recognising that reducing emissions and promoting sustainable practices ultimately contribute to alleviating the root causes of the crisis.

Given the sport's global reach and the strong public influence of professional athletes, tennis possesses significant potential to contribute to broader societal advocacy for climate action. By integrating climate considerations into governance, operations and education, the tennis community can play a meaningful role in promoting environmental awareness while modelling responsible adaptation within the sporting sector. As climate projections indicate that environmental challenges will continue to intensify, proactive, coordinated and science-based strategies are essential to ensure that tennis remains safe, fair and sustainable in the decades ahead.

Supplementary materials

Not applicable

Disclosure

Funding

The study received no funding and incurred no expenses unrelated to the publication costs for the author.

Author contributions

Mikołaj Patalong - conceptualization, methodology, software, formal analysis, writing - review and editing, formal analysis, supervision
Katarzyna Więckowska - investigation, resources, formal analysis
Paweł Pustuła - investigation, formal analysis, project administration
Wiktoria Michnowska - formal analysis, resources
Przemysław Kołodziej - formal analysis, resources
Mieszko Czapliński - investigation, data curation
Ewa Szplit - resources, writing - rough preparation
Andrzej Bilyk - resources, data curation
Natalia Bruska - data curation, writing - rough preparation
Roman Cemaga - data curation, visualization

All authors have read and agreed with the published version of the manuscript.

Informed consent statement

Not applicable.

Institutional Review Board Statement

Not applicable.

Data availability statement

Not applicable.

Conflict of interest

The authors declare no conflict of interest in relation to this study.

Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve grammar and language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

Institutional Review Board Statement

Not applicable.

References:

1. Kuyper, J., Schroeder H., Linnér, B.-O., (2018) The Evolution of the UNFCCC. Annual Review of Environment and Resources https://doi.org/10.1146/annurev-environ-102017-030119
2. Schipper, E.L.F. (2006), Conceptual History of Adaptation in the UNFCCC Process. Review of European Community & International Environmental Law, 15: 82-92. https://doi.org/10.1111/j.1467-9388.2006.00501.x
3. Romanello, M., Walawender, M., Hsu, S. C., Moskeland, A., Palmeiro-Silva, Y., Scamman, D., Ali, Z., Ameli, N., Angelova, D., Ayeb-Karlsson, S., Basart, S., Beagley, J., Beggs, P. J., Blanco-Villafuerte, L., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J. D., Chicmana-Zapata, V., Chu, L., … Costello, A. (2024). The 2024 report of the Lancet Countdown on health and climate change: facing record-breaking threats from delayed action. Lancet (London, England), 404(10465), 1847–1896. https://doi.org/10.1016/S0140-6736(24)01822-1
4. Orru, H., Ebi, K. L., & Forsberg, B. (2017). The Interplay of Climate Change and Air Pollution on Health. Current environmental health reports, 4(4), 504–513. https://doi.org/10.1007/s40572-017-0168-6
5. Walinski, A., Sander, J., Gerlinger, G., Clemens, V., Meyer-Lindenberg, A., & Heinz, A. (2023). The Effects of Climate Change on Mental Health. Deutsches Arzteblatt international, 120(8), 117–124. https://doi.org/10.3238/arztebl.m2022.0403
6. Dee, S. G., Nabizadeh, E., Nittrouer, C. L., Baldwin, J. W., Li, C., Gaviria, L., Guo, S., Lu, K., Saunders-Shultz, B. M., Gurwitz, E., Samarth, G., & Weinberger, K. R. (2022). Increasing Health Risks During Outdoor Sports Due To Climate Change in Texas: Projections Versus Attitudes. GeoHealth, 6(8), e2022GH000595. https://doi.org/10.1029/2022GH000595
7. The Carbon Footprint of the Games – International Climate Change Law and the Olympics https://doi.org/10.1017/aju.2020.71
8. Woodward, A., Smith, K. R., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., Olwoch, J., Revich, B., Sauerborn, R., Chafe, Z., Confalonieri, U., & Haines, A. (2014). Climate change and health: on the latest IPCC report. Lancet (London, England), 383(9924), 1185–1189. https://doi.org/10.1016/S0140-6736(14)60576-6

9. Brocherie, F., Pascal, M., Lagarrigue, R., & Millet, G. P. (2024). Climate and health challenges for Paris 2024 Olympics and Paralympics. BMJ (Clinical research ed.), 384, e077925. https://doi.org/10.1136/bmj-2023-077925
10. Crandall, C. G., & Wilson, T. E. (2015). Human cardiovascular responses to passive heat stress. Comprehensive Physiology, 5(1), 17–43. https://doi.org/10.1002/cphy.c140015
11. Kovacs M. S. (2006). Applied physiology of tennis performance. British journal of sports medicine, 40(5), 381–386. https://doi.org/10.1136/bjsm.2005.023309
12. Watanabe, K., Stöhr, E. J., Akiyama, K., Watanabe, S., & González-Alonso, J. (2020). Dehydration reduces stroke volume and cardiac output during exercise because of impaired cardiac filling and venous return, not left ventricular function. Physiological reports, 8(11), e14433. https://doi.org/10.14814/phy2.14433
13. Morante, S. M., & Brotherhood, J. R. (2007). Air temperature and physiological and subjective responses during competitive singles tennis. British journal of sports medicine, 41(11), 773–778. https://doi.org/10.1136/bjsm.2007.036996
14. Bergeron M. F. (2014). Hydration and thermal strain during tennis in the heat. British journal of sports medicine, 48 Suppl 1(Suppl 1), i12–i17. https://doi.org/10.1136/bjsports-2013-093256
15. Nowak A., Kennelley G., Krabak B., Roberts W., Tenforde K., Tenforde A. (2022). Endurance Athletes and Climate Change. The Journal of Climate Change and Health. 6. 100118. https://doi.org/10.1016/j.joclim.2022.100118
16. Lim C. L. (2020). Fundamental Concepts of Human Thermoregulation and Adaptation to Heat: A Review in the Context of Global Warming. International journal of environmental research and public health, 17(21), 7795. https://doi.org/10.3390/ijerph17217795
17. Racinais, S., Cocking, S., & Périard, J. D. (2017). Sports and environmental temperature: From warming-up to heating-up. Temperature (Austin, Tex.), 4(3), 227–257. https://doi.org/10.1080/23328940.2017.1356427
18. Cramer, M. N., Gagnon, D., Laitano, O., & Crandall, C. G. (2022). Human temperature regulation under heat stress in health, disease, and injury. Physiological reviews, 102(4), 1907–1989. https://doi.org/10.1152/physrev.00047.2021
19. Baldwin, J. W., Benmarhnia, T., Ebi, K. L., Jay, O., Lutsko, N. J., & Vanos, J. K. (2023). Humidity's Role in Heat-Related Health Outcomes: A Heated Debate. Environmental health perspectives, 131(5), 55001. https://doi.org/10.1289/EHP11807

20. Périard, J. D., Eijsvogels, T. M. H., & Daanen, H. A. M. (2021). Exercise under heat stress: thermoregulation, hydration, performance implications, and mitigation strategies. Physiological reviews, 101(4), 1873–1979. https://doi.org/10.1152/physrev.00038.2020
21. Alahmad, B., Khraishah, H., Althalji, K., Borchert, W., Al-Mulla, F., & Koutrakis, P. (2023). Connections Between Air Pollution, Climate Change, and Cardiovascular Health. The Canadian journal of cardiology, 39(9), 1182–1190. https://doi.org/10.1016/j.cjca.2023.03.025
22. John, G., Semenova, E. A., Mohamed, D. A., Georges Abi Antoun, T., Yusupov, R. A., & Ahmetov, I. I. (2025). Air Pollution and Its Impact on Health and Performance in Football Players. Sports (Basel, Switzerland), 13(6), 170. https://doi.org/10.3390/sports13060170
23. Reche, C., Viana, M., van Drooge, B. L., Fernández, F. J., Escribano, M., Castaño-Vinyals, G., Nieuwenhuijsen, M., Adami, P. E., & Bermon, S. (2020). Athletes' exposure to air pollution during World Athletics Relays: A pilot study. The Science of the total environment, 717, 137161. https://doi.org/10.1016/j.scitotenv.2020.137161
24. Kippelen, P., Fitch, K. D., Anderson, S. D., Bougault, V., Boulet, L. P., Rundell, K. W., Sue-Chu, M., & McKenzie, D. C. (2012). Respiratory health of elite athletes - preventing airway injury: a critical review. British journal of sports medicine, 46(7), 471–476. https://doi.org/10.1136/bjsports-2012-091056
25. Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Jay, O. (2021). Hot weather and heat extremes: health risks. Lancet (London, England), 398(10301), 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3
26. González-Alonso, J., Crandall, C. G., & Johnson, J. M. (2008). The cardiovascular challenge of exercising in the heat. The Journal of physiology, 586(1), 45–53. https://doi.org/10.1113/jphysiol.2007.142158
27. Mason, H. M., King, J. C., Peden, A. E., Leicht, A. S., & Franklin, R. C. (2024). The impact of extreme heat on mass-gathering sporting events: Implications for Australia and other countries. Journal of science and medicine in sport, 27(8), 515–524. https://doi.org/10.1016/j.jsams.2024.04.015
28. Wen, M., Liu, G., Li, W., Xie, T., Zhang, Y., Qin, F., & Zhao, J. (2022). Effects of mixed-cooling strategies on executive functions in simulated tennis in hot and humid conditions. Frontiers in physiology, 13, 1008710. https://doi.org/10.3389/fphys.2022.1008710

29. Girard, O., Christian, R. J., Racinais, S., & Périard, J. D. (2014). Heat stress does not exacerbate tennis-induced alterations in physical performance. British journal of sports medicine, 48 Suppl 1(Suppl 1), i39–i44. https://doi.org/10.1136/bjsports-2013-093165
30. Nadgir, N. (2024). Analyzing the impact of rising temperatures on tennis performance and athlete health. Journal of High School Science, 8(3), 108-130.
31. Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., & Thomas, K. (2017). Etiology and Recovery of Neuromuscular Fatigue following Competitive Soccer Match-Play. Frontiers in physiology, 8, 831. https://doi.org/10.3389/fphys.2017.00831
32. Lambrich, J., Muehlbauer, T. (2025). Effects of fatigue on physiological, physical fitness, and stroke performance related parameters in healthy tennis players: a systematic review and meta-analysis. Frontiers in sports and active living, 7, 1578914. https://doi.org/10.3389/fspor.2025.1578914
33. González-Alonso, J., Mora-Rodríguez, R., & Coyle, E. F. (2000). Stroke volume during exercise: interaction of environment and hydration. American journal of physiology. Heart and circulatory physiology, 278(2), H321–H330. https://doi.org/10.1152/ajpheart.2000.278.2.H321
34. Trangmar, S. J., Chiesa, S. T., Llodio, I., Garcia, B., Kalsi, K. K., Secher, N. H., & González-Alonso, J. (2015). Dehydration accelerates reductions in cerebral blood flow during prolonged exercise in the heat without compromising brain metabolism. American journal of physiology. Heart and circulatory physiology, 309(9), H1598–H1607. https://doi.org/10.1152/ajpheart.00525.2015
35. Naito, T., Saito, T., Morinaga, H., Eda, N., & Takai, Y. (2024). Elevated core temperature in addition to mental fatigue impairs aerobic exercise capacity in highly trained athletes in the heat. Journal of physiological anthropology, 43(1), 30. https://doi.org/10.1186/s40101-024-00377-0
36. Gibson, O. R., James, C. A., Mee, J. A., Willmott, A. G. B., Turner, G., Hayes, M., & Maxwell, N. S. (2019). Heat alleviation strategies for athletic performance: A review and practitioner guidelines. Temperature (Austin, Tex.), 7(1), 3–36. https://doi.org/10.1080/23328940.2019.1666624
37. Orr M, Inoue Y, Seymour R, Dingle G. Impacts of climate change on organized sport: a scoping review. Wiley Interdiscip Rev Clim Change. (2022) 13(3):e760. https://doi.org/10.1002/wcc.760

38. Larneby, M., Svensson, D., & Hedenborg, S. (2025). Challenges, tensions and opportunities: sport and climate change. Sport in Society, 28(10), 1429–1433. https://doi.org/10.1080/17430437.2025.2560751
39. Mallen, C., & Dingle, G. (2021). Organizing Sport for Climate Related Adaptations: Lessons from the Water and Forestry Industries. Sustainability, 13(18), 10462. https://doi.org/10.3390/su131810462
40. Bandiera, D., Racinais, S., Garrandes, F., Adami, P. E., Bermon, S., Pitsiladis, Y. P., & Tessitore, A. (2024). Heat-related risk at Paris 2024: a proposal for classification and review of International Federations policies. British journal of sports medicine, 58(15), 860–869. https://doi.org/10.1136/bjsports-2024-108310
41. Gollagher, P., Fastenrath, S. (2023). Transformative climate resilience and sport mega-events–the case of the Australian open. Environmental Innovation and Societal Transitions, 48, 100762. https://doi.org/10.1016/j.eist.2023.100762
42. Wilby, R. L., Orr, M., Depledge, D., Giulianotti, R., Havenith, G., Kenyon, J. A., Matthews, T. K. R., Mears, S. A., Mullan, D. J., & Taylor, L. (2023). The impacts of sport emissions on climate: Measurement, mitigation, and making a difference. Annals of the New York Academy of Sciences, 1519(1), 20–33. https://doi.org/10.1111/nyas.14925