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Mougin, Loïs; Bougault, Valérie; Racinais, Sébastien; Mountjoy, Margo L.; Stephenson, Ben et al

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Environmental challenges facing athletes, stakeholders and spectators at Paris 2024 Olympic and Paralympic Games: an evidence-based review of mitigation strategies and recommendations

Loïs Mougin ¹, Valérie Bougault ², Sébastien Racinais ^{3,4},
Margo L Mountjoy ⁵, Ben Stephenson ^{1,6}, Sarah Carter ⁷, Lewis J James ¹,
Stephen A Mears ¹, Lee Taylor ^{1,8}

¹School of Sport, Exercise and Health Sciences, National Centre for Sport and Exercise Medicine, Loughborough University, Loughborough, UK

²LAMHCESS, Université Côte d'Azur, Nice, France

³Environmental Stress Unit, CREPS Montpellier Font-Romeu, Montpellier, France

⁴DMEM, UMR 866 INRAE / University of Montpellier, Montpellier, France

⁵Department of Family Medicine, McMaster University, Hamilton, Ontario, Canada

⁶UK Sports Institute, Loughborough, UK

⁷Faculty of Health, Exercise and Sports Science, Charles Darwin University, Darwin, Northern Territory, Australia

⁸University of Technology Sydney, Sydney, New South Wales, Australia

Correspondence to

Dr Lee Taylor;
l.taylor2@lboro.ac.uk

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ABSTRACT

The upcoming Paris 2024 Olympic and Paralympic Games could face environmental challenges related to heat, air quality and water quality. These challenges will pose potential threats to athletes and impact thousands of stakeholders and millions of spectators. Recognising the multifaceted nature of these challenges, a range of strategies will be essential for mitigating adverse effects on participants, stakeholders and spectators alike. From personalised interventions for athletes and attendees to comprehensive measures implemented by organisers, a holistic approach is crucial to address these challenges and the possible interplay of heat, air and water quality factors during the event. This evidence-based review highlights various environmental challenges anticipated at Paris 2024, offering strategies applicable to athletes, stakeholders and spectators. Additionally, it provides recommendations for Local Organising Committees and the International Olympic Committee that may be applicable to future Games. In summary, the review offers solutions for consideration by the stakeholders responsible for and affected by the anticipated environmental challenges at Paris 2024.

INTRODUCTION

Unprecedented logistical and environmental challenges were faced at the Tokyo 2020 Olympic and Paralympic Games.¹ These included heat,¹ humidity² and air quality³ from an environmental perspective and a myriad of logistical factors due to the COVID-19 pandemic.⁴ Similar or greater environmental challenges could be faced at the Paris 2024 Olympic and Paralympic Games (July–September 2024).⁵ Indeed, Paris is a city particularly affected by climate change,⁶ facing heat-related and air and water quality issues at many competition venues.⁷ Many of these factors have been shown to compromise the health of athletes,^{2,8,9} decrease elite athlete performance (mainly endurance and outdoor team athletes^{10,11}) and/or affect the health of other attending stakeholders.¹² Therefore, varied inter-related environmental and associated logistical challenges will be encountered at Paris 2024 by athletes, stakeholders (ie, volunteers, practitioners, on-site workers and journalists) and spectators, including, but not limited to: (1) varied physical and physiological event requirements; (2)

WHAT IS ALREADY KNOWN

- ⇒ As seen at prior Olympic and Paralympic Games, a variety of location and sport-specific environmental challenges are experienced by athletes, stakeholders and spectators.
- ⇒ Paris will be no exception, with expected environmental challenges fluctuating and often combining within and between days of the Games period, presenting a variable challenge to maintain the health and performance of athletes, stakeholders and spectators.
- ⇒ Paris is a climate changed city and many of these environmental challenges have intensified over recent years (even since Paris was awarded the Games officially in September 2017).

WHAT ARE THE NEW FINDINGS

- ⇒ Extremes of heat, humidity, air and water pollution are likely at some point during Paris 2024, and although the environmental conditions could be fortuitously favourable from a Games perspective (eg, temperate, low rain fall, good air quality), this is unlikely and all attendees must be prepared appropriately and supported by evidence-informed Local Organising Committee/International Olympic Committee-facilitated infrastructure, logistics and policies.
- ⇒ There are a variety of evidence-informed recommendations that can be adopted by athletes, stakeholders and spectators to mitigate the negative health and performance effects of these environmental challenges.
- ⇒ Some athletes (eg, outdoor and/or endurance athletes) are more susceptible to the deleterious effects of these environmental challenges to their health and performance and could face combined environmental challenges (eg, triathletes could face heat, humidity, high ozone concentration and poor water quality).
- ⇒ Personal responsibility and organiser-delivered/facilitated infrastructure and policy are required to limit the negative effects of environmental extremes on the health and/or performance of all those attending Paris 2024.

diverse changeable environmental conditions; and (3) a myriad of athlete, stakeholder and spectator-specific factors (eg, sex, anthropometry, event/discipline/activity, competing/working/spectating, classification, acclimation status, medical history, type and severity of disability). Individualised (ie, based on the individual's needs and specificities), practitioner-led and evidence-informed practice will be required to optimise athlete, stakeholder and spectator health, and performance at Paris 2024. Therefore, this evidence-based review, drawing extensively from recent recommendations and consensus reached by expert groups, will:

- ▶ Outline specific environmental challenges that athletes, stakeholders and spectators may face at Paris 2024.
- ▶ Provide athlete-centred, practice-led and evidence-informed solutions to meet the above challenges.
- ▶ Provide stakeholder/spectator-centred, practice-led and evidence-informed solutions to meet the above challenges.
- ▶ Provide recommendations for Local Organising Committee (LOC) and International Olympic Committee (IOC) 'expert' groups.

ADOPTED METHODS AND APPROACHES

Data were obtained from a variety of sources (as indicated) including personal communication with experts outside of the authorship. Recommendations were initially outlined by authors LM and LT and whenever possible align with existing consensus, meta-analysis, reviews and best practices (as cited). Refinement and consensus between authors were reached via four rounds of author revisions. These recommendations (summarised in figures 1 and 2) are realised through a combination of best practice guidelines (as cited) and author experience (including but not limited to substantial involvement with elite athletes, Olympic/Paralympic sport and a variety of non-Olympic/Paralympic elite sports: sport practitioners, sport researchers/scientists, sport clinicians and medical doctors, and members of international federations, governing bodies, LOCs and IOC Olympic/Paralympic 'expert' groups). Limitations of these approaches are provided within the relevant section.

EDI statement

Our recommendations for Olympic and Paralympic athletes, as well as for all audiences, are developed with the aim of including and providing useful information to everyone. Our authors, including females and males and researchers with different backgrounds (young researchers, lecturers and professors), represent diverse perspectives from around the world.

PARIS 2024: HEAT STRESS EXPECTATIONS AND ASSOCIATED RISKS

Tokyo 2020 saw the hottest (hot/humid) Olympic and Paralympic Games on record.¹ When Paris was awarded the Games (13 September 2017), summer heatwaves were exceptional yet have occurred every year since (excluding 2021). Indeed, temperatures are widely predicted to exceed 30°C regularly across the Games (see figure 3) and may reach 40°C should a heatwave comparable to 2022 occur.¹³ Moreover, average relative humidity in Paris during the summer months is around 70–80%.¹⁴

Endurance (eg, road cycling, mountain biking, middle-distance running) and other sports with prolonged exposure to heat (eg, tennis, team sports) are scheduled for the afternoon and evening, when temperatures are expected to peak (temperatures >41°C observed after 19:00 hours in 2019). Thus, the likelihood of heat-related issues are significant. Additionally, staging some of Paris 2024 events in the city centre, such as triathlon, race walking and marathon, with limited shade and urban heat islands, could increase

the potential for heat-related problems further.¹⁵ However, some precautions have already been taken for some events, with for example triathlon and marathon start times altered to 08:00 hours.

A proxy of likely Paris 2024 conditions⁵ were seen at the 2023 World Athletics Championships in Budapest (19–27 August), where temperatures reached 35°C and 90% relative humidity (wet-bulb globe temperature (WBGT) >33.5°C; index accounting for air temperature, humidity, radiant heat and air movement, with values >31°C representing a very high to extreme risk of heat illness). At both Tokyo 2020 and Budapest 2023, significant countermeasures were taken by the international federations, IOC expert groups, LOCs (events changing time and locations, often with relatively short notice²) and athletes/practitioners (behavioural and interventional thermoregulatory strategies employed¹⁶). However, logistical changes do not always yield the desired effects (eg, WBGT remained >30°C in Sapporo during the relocated Tokyo 2020 Olympic walk and marathon events), resulting in 50 athletes out of 368 (48 of these 50 showing signs and symptoms of exertional heat illness (EHI) being transferred to a medical station.² Clearly, adapted policy can mitigate risks and the decline in athlete performance,¹⁷ but can fail if poorly planned and/or communicated. In addition, many Paralympic athletes are likely to be at greater risk of heat-related illnesses due to reduced thermoregulatory capacities (eg, reduced sweating capacity, lower convective surface area, additional sports equipment depending on their impairments¹⁸). Athletes/practitioners have a variety of long-term and short-term heat mitigation strategies to consider¹⁹ and ideally pilot/integrate into their event preparations.¹⁰

Although many athletes are most at risk of EHI because of their heat production during exercise, spectators and some stakeholders can also be affected by heat illness. At Paris 2024, a total of 45 000 volunteers and several million spectators²⁰ will attend the Games. Many of these are often less 'fit' than athletes, with different age, weight and both known and unknown medical challenges (ie, obesity, cardiovascular and respiratory diseases), potentially reducing their resistance to heat²¹ while increasing their risk of heat-related illnesses and mortality during heatwaves.²² This is particularly true when they (and other stakeholders) are not acclimatised to the heat²³ and have long heat stress exposure periods during spectating or other event responsibilities. If these long exposures are combined with inappropriate clothing (eg, is dark coloured, without sun projection and does not facilitate heat exchange), poor hydration practices and/or no sunscreen, among other factors outlined above, EHI becomes more likely.²³ Untreated and/or unrecognised heat illness can be fatal in athletes, spectators and stakeholders, even without engaging in physical activity. For example, prior to the Tokyo Olympics a mascot from an amusement park died of heat stroke.

Athlete-centred heat mitigation strategies

Long-term heat mitigation strategies

Two weeks of heat acclimation (ie, artificial exposure)/acclimatisation (ie, natural exposure) (HAc) provides the most robust performance and health protective effects during exercise in the heat.¹⁰ Typically, this entails undertaking 14 days of daily exercise (60–90 min) with a core temperature $\geq 38.5^\circ\text{C}$.²⁴ If active HAc is not possible for any/all sessions, other methods increasing core and skin temperatures, sweating and skin blood flow,^{10 24} such as passive HAc (eg, postexercise sauna $\geq 80^\circ\text{C}$ and/or hot water immersion $\geq 40^\circ\text{C}$ for ≥ 40 min²⁵), can be adopted for any/all sessions.²⁶ Passive HAc can be used to preserve the quality of the active part of an athlete's training (or those with extensive technical and

PARIS 2024 OLYMPIC AND PARALYMPIC GAMES: ATHLETE RECOMMENDATIONS AND STRATEGIES TO FACE ENVIRONMENTAL CHALLENGES



1. HEAT EXPOSURE

Long term:

- 2 Weeks *heat acclimation/acclimatisation*:
 - 60-90min exercise/day
 - Core temperature $\geq 38.5^{\circ}\text{C}$
- *Passive heat acclimation*:
 - Sauna $\geq 80^{\circ}\text{C}$ or water immersion $\geq 40^{\circ}\text{C}$; ≤ 40 min
- *Re-acclimation* just before event

Short term:

For endurance sports and sports with prolonged heat exposure

- Limit *dehydration*
- Use *pre- and mid-cooling*:
 - **Internal** (ice slurry/ice cold water ingestion)
 - **External** (immersion, ice vest, ice hat, ice filled towel, etc.)
 - **Perceptual** (menthol mouth rinse)
- *Optimise carbohydrate* feeding
- *Optimise electrolyte* feeding
- Practice *pacing and tactical strategies* in real/competition conditions
- Lower *duration/intensity* of warm-ups
- Use appropriate clothing, loose-fitting, light coloured, sun-protective, caps, and sunscreen
- Follow LOC recommendations



PARIS
2024



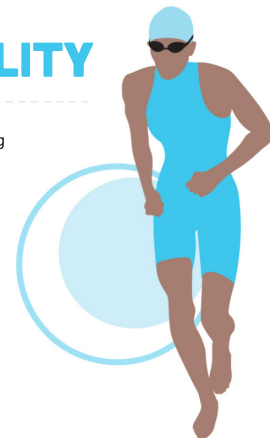
2. AIR QUALITY

- Monitor the *pollution* levels
 - Low-cost wearable sensors
- Limit *inhalation* (total dose) during training
 - Reduce *intensity/duration*
 - *Train in the morning* to avoid Ozone peak (avoid afternoon/evening)
 - Plan for *relocation* for high-intensity training
 - Train *indoors* where possible
 - 4-7 days prior to competition *acclimatise* with ozone
 - *Consume antioxidant* supplementation
 - Vitamin C and E, Beta-Carotene
- Limit *exposure* to infectious respiratory illness
 - Maintain physical distancing
 - Use hand wash, sanitiser, and face masks
 - Limit *inhalation* in daily life:
 - Close vehicle windows
 - Use cabin filters
 - Use air conditioning
 - Wear a face mask (N95, KN95, FFP2)
 - Follow LOC recommendations



3. WATER QUALITY

- Limit *exposure to poor quality water* during training
 - Number of sessions and duration
- *Relocate to alternative facilities* with clean water
 - Indoor facilities
 - *Monitor water quality*
- *Rehearse feeding* to limit the ingestion of water
- Prepare for *postponement or course modification*
- Limited *fully-suited* time



Environmental challenges facing athletes, stakeholders and spectators in Paris 2024 Olympic and Paralympic Games: An evidence-based review of mitigation strategies and recommendations'. Mouglin L et al. 2024

Figure 1 Athlete recommendations and strategies to face environmental challenges at Paris 2024 Olympic and Paralympic Games. LOC, Local Organising Committee.

PARIS 2024 OLYMPIC AND PARALYMPIC GAMES: SPECTATORS AND STAKEHOLDERS' RECOMMENDATIONS AND STRATEGIES TO FACE ENVIRONMENTAL CHALLENGES

1. HEAT EXPOSURE

- **Heat acclimatisation:**
 - Several short exposures before long exposures
- Stay hydrated and carry drinks to the venue
- **Cooling:**
 - **Internal** (ice slurry/ice cold water ingestion)
 - **External** (ice cold hat, ice filled towel, other cold items)
- **Limit heat exposure**
 - Stay in cool and/or shaded places
- Avoid overcrowded areas and hot surfaces
- Seek advice from medical services for heat stress in clinical populations:
 - Medications, disease, elderly, obese, etc.
- Wear appropriate clothing:
 - Loose-fitting, light coloured, sun-protective, sunglasses, and caps
- Use sunscreen:
 - Sun protection factor ≥ 25
- Follow LOC recommendations



2. AIR QUALITY

- Plan journeys to limit pollution exposure
- Spend more time in less-polluted places:
 - Green space
 - Blue space
 - Indoor well ventilated space
- Limit exposure to respiratory illness:
 - Maintain physical distancing
- Use hand wash, sanitiser, and face masks
 - Reduce time in overcrowded areas
 - Reduce time in confined spaces
- Use preventative treatments (e.g. vaccination)
 - Limit inhalation of pollutants in daily life:
 - Close vehicle windows
 - Use cabin filters in vehicles
 - Turn on air conditioning
- Wear a face mask (N95, KN95, FFP2)
- Follow LOC recommendations



Environmental challenges facing athletes, stakeholders and spectators in Paris 2024 Olympic and Paralympic Games: An evidence-based review of mitigation strategies and recommendations. Mouglin L et al. 2024

Figure 2 Spectators and stakeholders' recommendations and strategies to face environmental challenges at Paris 2024 Olympic and Paralympic Games. LOC, Local Organising Committee.

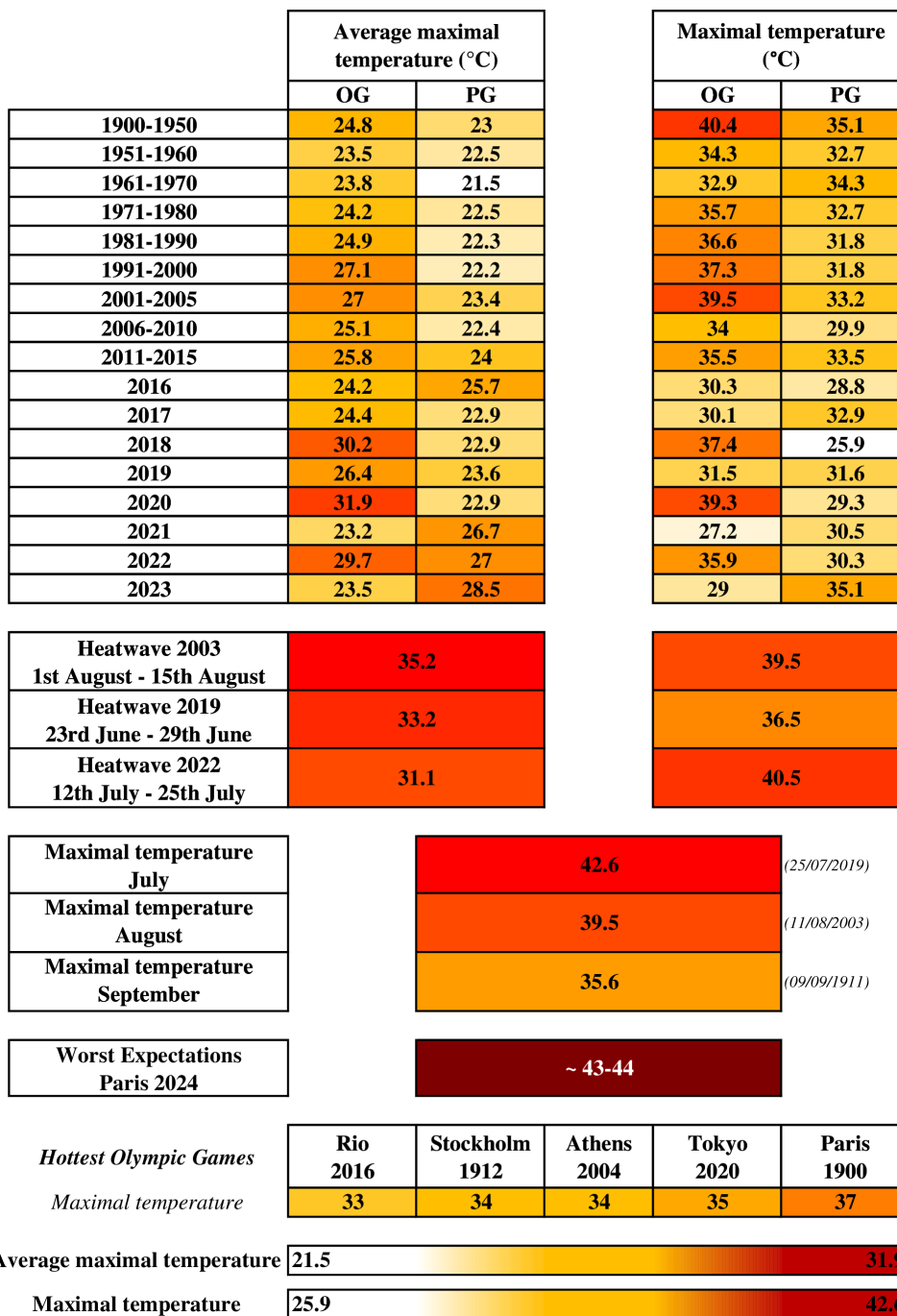


Figure 3 Temperature history and forecasts for Paris 2024.¹⁴ Average maximal temperature represents the daily maximal temperature over Olympic Games (OG) or Paralympic Games (PG) period. Worst expectations for Paris 2024.⁵ OG period: 27 July (first competition) to 11 August. PG period: 29 August (first competition) to 8 September.

tactical training requirements such as team sport athletes). This method is particularly useful to ‘top-up’ HAC during an athlete’s taper to avoid interference with the consolidation of adaptations procured through their final preparation/training phases (it may also be useful for non-endurance athletes, such as shorter distance or explosive events²⁶). With long-term HAC, heart rate and core temperature during exercise decrease, although from predominately non-elite samples, but similar responses are observed with elite athletes.²⁷ Self-reported HAC adoption resulted in fewer race withdrawals (ie, 19% vs 30%) and better performance (eg, ranked better; 18th vs 28th position) at several World Championship race

walking and running road race events.^{17 28} Meta-analytical review of performance improvements (mainly in endurance sports) suggests improvements of ~15% with short-term HAC (ie, <7 exposures), ~21% with medium-term HAC (ie, 8–14 exposures) and ~22% with long-term HAC (ie, >15 exposures²⁷). While short-term HAC can procure relevant adaptations, these are not as complete as long-term HAC and thus do not convey the same magnitude of health and performance benefits while their positive effects return to baseline (eg, decay) more quickly.²⁷ Given that 5–7 days of reacclimation are sufficient to regain acclimation after 2–3 weeks without heat exposure (after initial 2 weeks’ HAC), potential

HAc periodisation would include 2 weeks' HAc several weeks before competition, followed by 2 weeks of normal training (including some active/passive heat exposures) and 1 week of reacclimation before competitions,²⁹ provided the athletic taper is not compromised. Moreover, adaptations from HAc are not detrimental to endurance performance during temperate competition,³⁰ although whether they are advantageous has been debated.³¹ Although these recommendations are mainly aimed at improving performance in endurance sports or situations involving prolonged exposure to heat, HAc may be beneficial for non-endurance and non-outdoor events (for both Olympic and Paralympic athletes¹⁸), where it will improve thermal tolerance and comfort to heat stress during non-athletic activities of daily life and between heats of non-endurance competition, without detriment to athletic performance.^{26 32}

Short-term pre-event or competition-day focused strategies

To limit heat strain on the day of competition, several focused strategies can be used.³³ Precooling (~2–7.1%) and mid-cooling (~3.2–11.9%) can improve exercise performance in the heat^{34 35} across endurance and team sports,³⁶ yet precooling is detrimental for short-duration explosive efforts.³⁷ Although much of these data rely on non-elite athletes,³⁵ both precooling and mid-cooling are now used by many elite athletes at major events (ie, 80% of athletes adopted precooling and/or 93% used mid-cooling at the Doha 2019 IAAF World Athletics Championships³⁸; 77% of athletes used precooling or mid-cooling at Tokyo Paralympic Games¹⁶). These strategies can include various combinations of internal (eg, ice slurry/ice cold water ingestion), external (eg, immersion, ice vest, ice cold hat, ice filled towel and other cold exposures) and perceptual (eg, menthol mouth rinse) strategies.³³ When and how they are used are event and athlete specific whilst often limited by event rules and practice realities (eg, time and resource available). Illustrated evidence-informed examples for endurance and team sport athlete recommendations can be found elsewhere.^{33 39} In brief, precooling and mid-cooling strategies are piloted away from competition and integrated into an athlete's precompetition and during competition routine (eg, a phase change ice vest worn when a team sport player warms up before a game and at half time alongside ice slurry ingestion and ice towel application; ice slurry ingestion and ice towels in the 'call room' prior to and during road races). With all cooling manoeuvres, it is important to consider any unwanted side effects (eg, gastrointestinal (GI) disturbance, altered sweat response, disrupted pacing from central to peripheral sensation integration) and how altering thermal sensations through body cooling may alter heat-related illness risk; however, if done appropriately, the favourable core to skin temperature gradient elicited from effective mid-cooling should reduce heat-related illness risk.³⁸ Postexercise cooling can be used to accelerate acute athletic recovery, such as delayed-onset muscle soreness.³³

Cooling methods can be complemented by nutrition and hydration strategies to limit hypohydration to $\leq 2\%$ ⁴⁰ and to optimise electrolyte and carbohydrate feeding⁴¹ which must be preplanned according to individual responses, tolerances and race-specific needs. Behavioural strategies such as adapted pacing strategies are often naturally used in the heat,⁴² but specific and practised pacing and tactical strategies could contribute to prevent decreased performance.⁴³ Such pacing-related practice and ultimately race execution could be particularly challenging for Paralympic athletes with compromised peripheral-to-central

feedback processes and/or thermoregulation⁴⁴ or with intellectual impairments when executing defined pacing strategies. Ideally, all these interventions complement prior long-term HAc³³ and must be integrated into an environment-specific competition-day plan, undergoing extensive piloting reflective of the most challenging competition-day scenario. Other strategies on competition day include clothing (ie, light-coloured, loose-fitting, sun-protective clothing), sunscreen (ie, sun protection factor ≥ 25 using a water-based organic chemical sun filter), modified warm-up practices (ie, lower duration and/or intensity) and shade.²⁴

Stakeholders and spectator-centred heat mitigation strategies

Unlike most athletes, stakeholders and spectators may not be adequately aware of and/or prepared specifically for the weather at Paris 2024. Yet, potentially underpublicised and misunderstood heat-related risks may challenge stakeholders/spectators. For example, they are likely to stand/sit in a hot environment for several hours with limited or no natural/artificial shade, with compact viewing areas increasing heat and humidity and decreasing airflow, which together compromise evaporative cooling.²³ These risks present further in urban sports where artificial urban materials frequently reach temperatures ranging from 50°C to 80°C under intense solar radiation.⁴⁵ The HAc and cooling methods recommended for athletes (described earlier) are certainly of value to non-athletes, even if their implementation is sometimes complicated and requires certain precautions with at-risk populations. Advising spectators to: (1) limit their exposure to the heat by controlling time spent outside in hot temperatures⁴⁶; (2) wear appropriate clothing (including sunglasses and well-ventilated caps/hats) and sunscreen, as described above²⁴; (3) stay properly hydrated and carry non-alcoholic drinks to the venue; (4) avoid overcrowded areas (eg, the last kilometre of races) and urban materials (eg, concrete, brick, metal surfaces) where possible; and (5) protect themselves from high solar exposure using shaded areas with cooler surfaces including green and blue spaces (eg, trees and buildings, provided their surfaces remain cool and are not directly exposed to radiation²³) all appear prudent. Additionally, those taking medications should understand their possible undesirable interaction effects on thermal tolerance/responses (eg, altered thermoregulatory control⁴⁶). Comprehensive and individualised precautions, to be discussed with medically qualified personnel, should also be taken by people with obesity, cardiovascular disease, respiratory disease, diabetes and those ≥ 60 years old, who are particularly susceptible to thermal stress and related illnesses.⁴⁷

Recommendations for LOC and IOC 'expert' groups

In the event of extreme competition-day heat, the priorities of the organisers, medically qualified personnel and the LOC will be to avoid an unmanageable number of heat-related problems for athletes, stakeholders and spectators. This approach should encompass prevention, management and treatment of heat-related illnesses. Prevention involves implementing evidence-informed education and effective communication strategies about heat risks, cooling strategies and benefits of HAc, as provided by IOC, World Athletics and World Triathlon at previous events.²⁴ In previous events held in hot/humid environments, such as the Doha 2019 World Athletics Championships (ie, WBGT 23–31°C), 37% of athletes (ie, marathon runners and race walkers) did not have a dedicated heat preparation period¹⁷ despite the predicted and observed conditions markedly

increasing their vulnerability to heat-related illnesses and performance decrements. Clearly showing that not all elite athletes adopt evidence-informed preparation strategies,¹⁷ in part due to a variety of barriers (eg, climate, cost, knowledge) which are discussed elsewhere.³⁹ During Paris 2024, organisers will have to work closely with the meteorological services and set up on-site weather stations to provide detailed yet understandable weather forecasts. Detailed forecasts (including worst-case scenarios) will be imperative for long-term planning (ie, weeks prior to the event) to develop effective pre-event mitigation strategies and short-term/real-time decision-making (ie, days and hours leading up to the event) for competition-day athlete, stakeholder/spectator and LOC decision-making alongside practical recommendations.

Across competition venues, diverse microclimate environments are seen in part through an array of competition surfaces, related built environments and spectator seating/standing. These hyperlocal and location-specific data must be representative of the real-world/real-time competition environment that will be encountered by the athlete and other stakeholders/spectators at each specific venue²⁴; ideally accurate predictions to enable planned rather than reactive decision-making. Policies and procedures for schedule and venue changes to lower heat-related risk should be planned and shared widely in advance to athletes' staff, to ease their integration into athlete competition-day preparations. During competitions, organisers should provide freezers for ice jackets and drinks in the start/finish/competition areas and refuelling zones, to aid athlete cooling and encourage teams to monitor athlete core temperature through ingestible telemetric thermometer pills (although adoption is costly and may be out of reach for some athletes/federations). Moreover, for athletes as well as stakeholders and spectators, shaded areas, readily accessible water fountains and ice dispensers, sunscreen, caps, umbrellas and air blowers should be provided,^{23 38} in addition to enabling them to carry non-alcoholic drinks freely to, within and between venues. Organisers should ensure that appropriate clothing, as described above, is provided for volunteers and other stakeholders who are wearing additional mandatory items such as bibs. Heat can, in a situation-dependent manner, affect spectators and Games volunteers to a greater extent⁴⁷ than athletes (due to longer exposure times) and evidently in potentially greater numbers.⁴⁸ Education and specific training for medical services, but also for volunteers and spectators about heat stroke detection, will be essential for early recognition (ie, signs and symptoms) and effective treatment. Heat stroke management and treatment protocols require medically qualified personnel (ie, four caregivers for one patient) and organisers to be well equipped for rapid cooling (ie, cold water baths) before hospital transfer,⁴⁹ for both athletes and other at-risk stakeholders and spectators. For quick transfer of collapsing athletes, a wheelchair to starters ratio of 1:5 is recommended.¹⁷ Rectal temperature probes will be necessary to assess core temperature accurately and continuously. Lowering core temperature will mainly require immersion in cold water. In Tokyo 2020, >20 tonnes of ice were used at the competition venues and ~2200 kg/day for the Athlete Village Polyclinic.²⁴ A similar, if not higher, quantity should be pre-emptively planned for Paris 2024. Use of a point-of-care blood analysis device is also recommended for conducting blood sodium and blood glucose analysis to differentially diagnose the collapsed athlete's medical condition to transfer only people requiring hospitalisation.⁴⁹

Table 1 Annual mean of air pollutants in Paris in 2022 compared with World Health Organization (WHO) recommendations and Tokyo 2021

Pollutant	WHO recommendations (2021), $\mu\text{g}/\text{m}^3$	Situation in Tokyo (2021), $\mu\text{g}/\text{m}^3$	Situation in Paris (2022), $\mu\text{g}/\text{m}^3$
Particulate matter (PM ₁₀) (annual mean)	15	85	20
Particulate matter (PM _{2.5}) (annual mean)	5	23	12
Nitrogen dioxide (NO ₂) (annual mean)	10	23	>40
Ozone (O ₃) (8-hour mean)	100	59	>120

PARIS 2024: AIR POLLUTION EXPECTATIONS AND ASSOCIATED RISKS

As the Athlete Village at Paris 2024 will not have air-conditioning, it is plausible fans and open windows will be a predominant method of cooling and that athletes will spend considerable time outside in shaded and naturally ventilated areas. Therefore, while pollution per se may be lower in Paris compared with Tokyo, total exposure could be markedly higher in Paris (see [table 1](#) for specific comparisons). Marathon runners, walkers and triathletes may face heightened risks, especially since these events typically occur in the early morning when particulate matter (PM) concentrations peak due to rush hour traffic. In addition to endurance sports, athletics and outdoor team sports (among several other) events entail particular risk, as they will take place during pollution peaks (ie, ozone (O₃) and PM, in the afternoon and evening) in stadiums located near major roads.

Air quality is determined by the concentrations of various pollutants, most notably by nitrogen dioxide (NO₂), O₃ and PM with a diameter of less than 10 (PM₁₀) or 2.5 (PM_{2.5}) μm . O₃ is generally the dominant pollutant on sunny, warm days, with a uniform regional distribution, while PM and NO₂ tend to display a more localised distribution depending on meteorological conditions, vehicle traffic and other emission sources. The 2008 Beijing Olympic and Paralympic Games took place in a highly air-polluted location, although air quality improved during the Games.⁵⁰ This led to considerable interest in the effects of air quality on athletes' health and performance prior to Beijing.⁸ The air quality is less a concern in Paris than Beijing. However, as with most capital cities in Western Europe, yearly air quality in Paris is above WHO-recommended levels ([table 1](#)⁵¹), with O₃ concentrations above those observed in Tokyo in 2021,⁵² although the situation has improved over the last 10 years (eg, -30% in NO₂). Moreover, O₃ concentrations are increased during extreme climate events (eg, 2022 Paris heatwave) and exacerbated with associated anticyclonic events while PM concentration may be increased by specific events such as wildfires.⁵³ Other compounding factors include the increase in transport-related pollution during the Games,⁵⁴ especially around highways and similar motor transport congestion areas. Although a planned reduction in traffic at the competition venues could lead to a reduction in PM concentrations, this could also lead to adverse effects such as an increase in O₃ concentrations.⁵²

Health effects associated with various pollutants are contingent on factors such as their nature (ie, O₃ and PM may affect different populations), concentration and duration of exposure. Millions of spectators may be exposed to air pollution at Paris 2024,

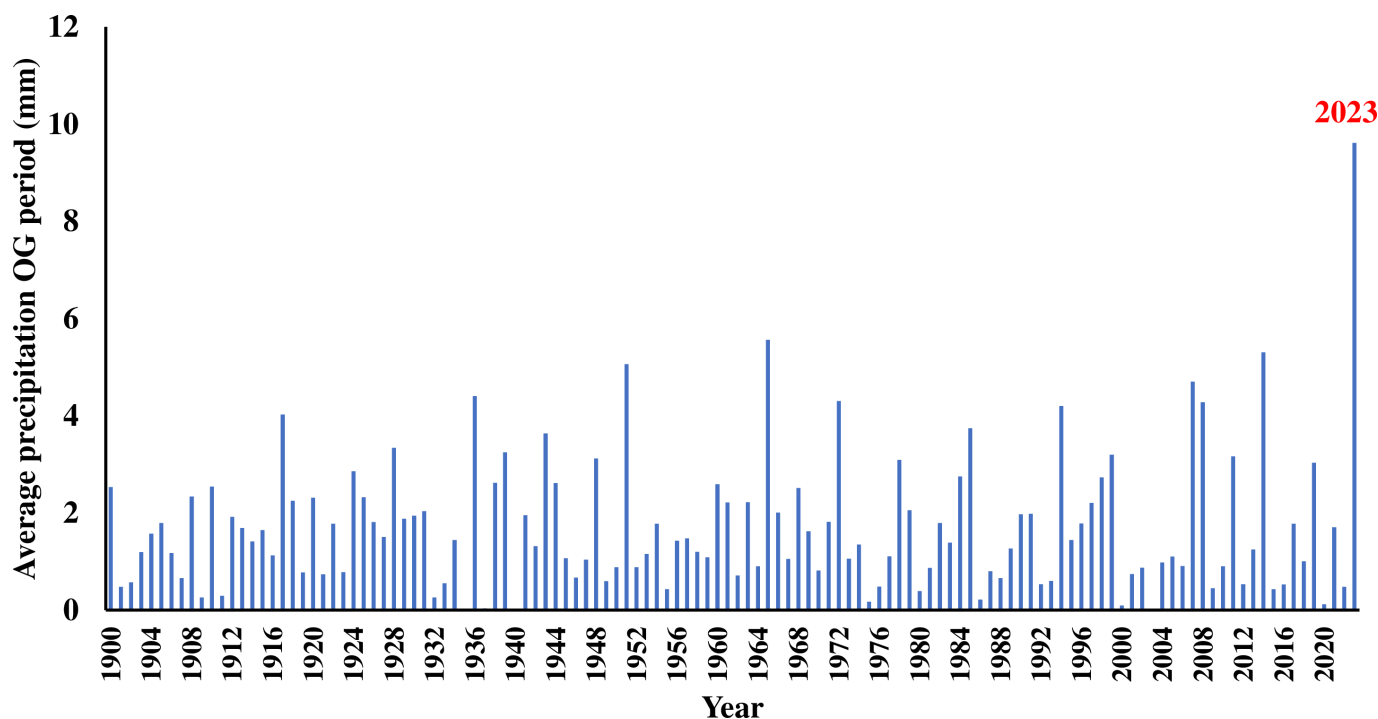


Figure 4 Average precipitation during Olympic Games (OG) period (27 July to 11 August) since 1900.

increasing their risks of respiratory and cardiovascular diseases, morbidity and mortality,^{55–57} although these risks increase in the case of long-term exposure. In addition to affecting spectators, effects could be exacerbated for athletes. In a systematic review of randomised controlled trials, specific evidence of O₃ exposure having deleterious effects on respiratory symptoms and lung function while exercising was reported, without such effects for other pollutants.⁵⁸ Further, some individuals were more susceptible to these effects than others.⁵⁹ Indeed, some athletes (particularly endurance athletes) appear very susceptible even at low concentrations of O₃.⁵⁹ Despite this variance, generally a dose–response is seen with higher concentrations eliciting more severe negative symptomology in endurance athletes. Together, these data suggest air pollution (especially in sensitive athletes) deleteriously affects athlete health⁸ and performance (eg, maximal or optimal performance capacity across a variety of sports⁶⁰). Mechanistically, acute air pollution exposure (with pollutant specificity) can reduce oxygen delivery to tissues, increase oxidative stress and inflammation⁶¹ and increase respiratory-related symptomology (eg, asthma, lung inflammation and nose and throat irritation⁶²) alongside eye discomfort and skin sensitivity.⁸ Moreover, athletes with exercise-induced bronchoconstriction (mainly endurance athletes⁶³) may be more sensitive to the effects of some pollutants when exercising.⁶⁴ In addition, in the context of the Summer Olympic Games, infectious respiratory illnesses represent up to 50% of acute symptom medical consultations,⁶⁵ largely due to known risks associated with travelling and mass gatherings (>15 000 expected athletes at the 2024 Olympic and Paralympic Games⁶⁶) alongside unfavourable changes in immunity and microbiota states through intensive physical training.⁶⁷ Air pollution may increase the risk of respiratory virus infections and severity, concerning to athletes and the general population.⁵⁵

Athlete-centred air pollution mitigation strategies

Hung *et al*⁶⁸ recently suggested acute strategies to mitigate air pollution effects by limiting the total inhaled dose during training

(ie, reduce exposure by time, exercise in the morning, reduce the intensity). Here, O₃ peaks should be avoided in the afternoon and early evening, when pollutant levels are at their highest, and high-intensity training should be relocated (including relocation inside) when required (facilitated by monitoring pollution levels and following organisers' advice) and feasible (eg, resource and facility availability). Considering air pollution could negatively affect many athletes, consideration prior to the games of alternative facilities outside the Paris area to avoid pollution peaks, as well as familiarisation to alternative sessions (eg, running on a treadmill rather than outside), appears prudent. Athletes and staff should be guided by the LOC's recommendations, regarding pollutant concentration, to adapt their training time and location.

Before and after training and competition, some strategies exist to limit PM inhalation by reducing exposure within accommodation and/or during transport and should be used by everyone (ie, those who take part in outdoor competitions, but also indoors). These include closing vehicle windows, using cabin filters, turning on air-conditioning (although the Paris 2024 Athlete Village will not have air-conditioning) and wearing a face mask (ie, N95, KN95 and FFP2 masks can remove 14–96% of PM depending on the mask, and its correct use⁶⁹), especially when local PM concentrations are high. Masks may also reduce infection propagation. It should be noted that wearing a mask can cause dyspnoea in high temperatures, especially if people are active.⁷⁰ O₃ acclimatisation (ie, repeated exposures to O₃) could be used in athletes before competition.^{3 71} Typically, arriving 4–7 days in advance of their competition and/or living in a country with similar conditions may help athletes to acclimate, mitigating to some degree the acute effects on respiratory symptoms, lung function and physiological parameters of performance.⁷² However, there is a lack of evidence on the use of acclimatisation for athletes with asthma. Nutrition strategies such as consuming antioxidant supplementation^{68 73} could also be used, although there is a lack of data exploring

Table 2 Recommendations for IOC and LOC to face heat, air pollution, poor water quality and hot water

Heat mitigation strategies	<ul style="list-style-type: none"> ▶ Provide evidence-based information about risks and strategies. ▶ Provide 'global' forecasts. ▶ Provide field of play forecasts. ▶ Plan for changes in schedule and location. ▶ Provide shaded areas. ▶ Provide readily accessible water fountains and ice dispensers, freezers, sunscreen, caps, umbrellas and air blowers. ▶ Enable spectators to carry non-alcoholic drinks to the venue. ▶ Be prepared for heat stroke management. <ul style="list-style-type: none"> – Sufficient wheelchairs for collapsing individuals. – Rectal temperature probes. – Cold water baths. – Blood analysis devices. – Sufficient medically qualified personnel (4 caregivers for 1 patient). – Large quantities of ice available.
Air pollution	<ul style="list-style-type: none"> ▶ Provide evidence-based information about risks and strategies. ▶ Provide 'global' and detailed forecasts. ▶ Provide access to indoor facilities. ▶ Facilitate athletes' transport to minimise time breathing particulate matter. ▶ Consider alternative venues or rescheduling options. ▶ Favour low/no emission vehicles. ▶ Encourage access with public transport. ▶ Reinforce the restriction of vehicles near competition venues. ▶ Plan for face mask distribution.
Poor water quality and hot water	<ul style="list-style-type: none"> ▶ Provide daily water quality data. ▶ Provide evidence-based information about risks and strategies. ▶ Provide access to indoor facilities. ▶ Consider alternative venues or rescheduling options.

IOC, International Olympic Committee; LOC, Local Organising Committee.

pollutant supplement-specific effects. In one of the limited data sets in this space, Hung *et al*⁶⁸ suggested consuming vitamin C (250–600 mg) and vitamin E (75–100 mg), and beta carotene (25 mg) the week before events to limit air pollution effects on performance.

Given that respiratory illnesses are prevalent in athletes, and that air pollutants may trigger respiratory symptoms (eg, asthma symptoms) in a dose-dependent manner,⁸ precautions to limit acute respiratory illness should be adopted, such as physical distancing, hand washing, alcohol-based hand sanitiser and face masking (for PM or virus infections).

Stakeholders and spectator-centred air pollution mitigation strategies

Due to the large number of visitors expected at Paris 2024, congested transport systems are likely, increasing travel time to competition venues and exposure to pollution for all stakeholders and spectators (ie, high concentrations of PM in metro stations). As for athletes, mitigation strategies against PM such as closing vehicle windows, using cabin filters, turning on air-conditioning and wearing a face mask (as described above) could/should be used. Planification of spectator's journeys (ie, time and route) should be determined in advance to limit time in places with poor air quality. To limit PM exposure during the day, spectators should also maximise their time in less polluted places (eg, parks, green and blue spaces when PM or NO₂ is high, indoor well-ventilated modern spaces with closed windows when O₃ is high) between competitions. Since air pollution could exacerbate acute respiratory illness symptoms, strategies such as limiting time spent in confined spaces and overcrowded areas (eg, bus and subway), and preventive treatments and up-to-date vaccination before travelling to these types of events⁴⁶ could constitute potential solutions for limiting respiratory illnesses which would be exacerbated by high air pollution.

Recommendations for LOC and IOC 'expert' groups

Unlike heat, which is near ubiquitously measured, pollution data require targeted attention to limit athletes' exposure. Organisers need to closely monitor air quality forecasts (accurate predictions would enable planned rather than reactive decision-making) and real-time assessments in key locations such as the Olympic and Paralympic Village, competition venues and training facilities with low-cost wearable air pollution sensors (an objective sensor evaluation has been provided by South Coast Air Quality Management District - <http://www.aqmd.gov/aq-spec/sensors>) and/or with permanent air pollution sensors, similar to the one installed by World Athletics at the Nice Stadium (France). Daily communication, including PM and O₃ concentrations and recommendations mainly based on WHO guidelines, of specific locations (especially for PM) and times to be avoided due to poor air quality will be paramount for the well-being of athletes, stakeholders and spectators. Educating athletes, stakeholders and spectators about the risks and mitigation strategies, employing informative infographics, such as presented in figures 1 and 2, may help raise awareness. Organising committees can also minimise exposure to pollution by providing access to indoor training facilities when pertinent, facilitating efficient athlete transport to minimise time spent in heavily polluted areas (with high PM concentration) and considering alternative venues or rescheduling options in the case of major weather events.⁶⁸ LOC should also consider preventive measures to limit localised PM concentration peaks by favouring low/no emission vehicles, encouraging access with public transport and reinforcing the restriction of vehicles near competition venues. Distribution of masks (N95, KN95, FFP2) may also be planned in case of PM concentration peaks at competition venues and in the Olympic and Paralympic Village for athletes, stakeholders and spectators.

PARIS 2024: WATER QUALITY AND TEMPERATURE EXPECTATIONS AND ASSOCIATED RISKS

Since the announcement of open water swimming (OWS) events in the Seine River (in late 2017), concerns have loomed over the water quality,⁷⁴ where swimming has been prohibited since 1923 (although some events such as Paris triathlon and 'Traversée de Paris à la nage' have recently taken place). Water events at the Olympic Games have already had to contend with water pollution, most notably at the 2016 Rio Games,⁷⁵ but the situation at Paris 2024 is unprecedented due to heavily urbanised waterways, resulting in degraded water quality (high concentration of faecal bacteria⁷⁶). In 2023, merely a year before Paris 2024, water quality on event sites was deemed unacceptable for 12 out of 27 days during the Olympic and Paralympic periods according to thresholds established by World Triathlon and World Aquatics, which rely on bacterial indicator organisms (ie, *Enterococci* >400 cfu/100 mL and *Escherichia coli* >1000 cfu/100 mL). Even more concerning, *E. coli* levels reached 2567 and 2759 cfu/100 mL, respectively, on the days of the men and women's triathlon events (ie, 6–7 August). During summer 2023, poor water quality led to the cancellation of the OWS World Cup event (6 August) and modification of the paratriathlon test event to a duathlon (19 August) in the Seine River, due to exceptional heavy rain and a default to sewer valves opening directly into the Seine. During heavy rainfall events, more likely due to climate change (figure 4) such as on 28 July 2023 (when 48 mm of rain occurred), *E. coli* levels spiked to 8464 cfu/100 mL, posing a significant health and performance risk to athletes.⁹ Likely illnesses from faecal bacteria include GI symptoms,⁷⁷ eye and skin infections and respiratory illnesses.⁷⁸ Aquatic athletes are at risk of water ingestion during competition (ie, during 15–40 min of swimming, 75% of the triathletes reported water ingestion⁷⁹), exposing them to a myriad of potential pathogens. Regarding on-water events (eg, canoeing, kayaking and rowing), these are taking place outside of major cities, in places where there are fewer heavily urbanised waterways, making the risks associated with poor water quality lower.

In addition to water quality, the Seine River temperature can now reach 27.5°C during summer heatwaves (~27.7°C for 10 days in 2003 and above 26°C every year since 2017⁸⁰). Although these temperatures permit triathlon and OWS competitions (World Aquatics permitted temperature range: 16–31°C; World Triathlon: 12–32°C), 'hot' water could be of concern for aquatic athletes (potentially exacerbated by combined exposure to poor-quality water). In triathlon, wet suits are not permitted with water >20°C (distance ≤1500 m) and >18°C in OWS. Water temperatures exceeding 20°C can contribute to the enforcement of the rule outlined previously (ie, wet suits not allowed), resulting in an increased skin surface area exposed to poor water quality. Additionally, elevated water temperatures pose an increased risk of hyperthermia due to compromised evaporative heat loss through immersion during swimming⁸¹ and greater radiant heat gain with black wet suits in OWS.⁹

Athlete-centred water quality mitigation strategies

As with air pollution, athletes will have to minimise exposure to poor water quality⁸² by training in clean water venues (ie, indoors or by monitoring water quality) which will also limit inadvertent consumption of poor-quality/polluted water. This latter item could further be improved by rehearsing and optimising feed zone practice. Athletes should also be aware of the high probability of logistical changes such as postponement (eg, due to a weather event) or course modifications (eg, alternative

courses and entry/exit points⁸²). Regarding hyperthermia risks, in addition to the cooling strategies detailed in part 1, athletes should limit fully suited time.⁹

Recommendations for LOC and IOC 'expert' groups

At Tokyo 2020, water quality prior to the Olympic Games was poor, leading to the modification of the paratriathlon test event to a duathlon (swim section replaced by a second run) in 2019. However, the organisers managed to remedy this for the Tokyo 2020 Olympic and Paralympic Games by maintaining water quality in the Odaiba Bay within the required safety thresholds. This was accomplished by using a triple layer barrier system to block bacteria from entering the precise area where the swim competition was seen. Moreover, the city of Tokyo updated its sewer system to increase its capacity to divert overflow sewage from flowing directly into the Bay, as can occur during heavy rainfall; clearly, a complex and costly solution requiring years of thought and execution. Due to the major threat posed by heavy rainfall to water quality at Paris 2024, the city of Paris has endeavoured to make similar progress to Tokyo in making the Seine swimmable over the last decade (ie, €1.4 billion invested over 10 years⁸³). However, organisers will not know how effective these new strategies (eg, a 50 000 m³ tank under construction to intercept urban run-off⁸³) will be in the event of heavy rainfall before the Olympic Games. As with air pollution, organisers must be ready to adapt the programme and venues in the case of major weather events. Furthermore, in addition to providing athletes with daily water quality data and recommendations, education by the LOC, aimed at enhancing risk comprehension, awareness and familiarity with mitigation strategies (via infographic as presented in figure 1) will be instrumental in mitigating potential water quality issues. In case of heavy rainfall and transiently polluted water, access to clean water swimming facilities should be provided for athlete training.

LIMITATIONS

The quality and level of evidence, as well as the risk of bias, were not formally assessed, which may affect the reliability of our recommendations. The recommendations provided are based on expert consensus, meta-analysis, reviews and best practices, but despite the diversity of the author panel, potential biases may exist, reflecting predominant views and possibly overlooking alternative approaches. Additionally, the generalisability of these recommendations to locations other than Paris is uncertain due to varying environmental and cultural factors.

CONCLUSION

Most athletes, regardless of their sport, will likely be affected by environmental challenges at the Paris 2024 Olympic and Paralympic Games, whether within and/or outside of their training and competition. Endurance athletes appear to be particularly susceptible to the adverse effects of environmental factors. However, it is essential to acknowledge that all athletes, to varying degrees, may experience impacts on their health and performance due to environmental conditions. Some athletes, such as triathletes, could face a combination of factors such as heat, high O₃ concentration and poor water quality.

These challenges will affect athletes and spectators, Games volunteers, practitioners and a myriad of other stakeholders. All of these will require both personal and organiser-delivered/facilitated strategies to limit negative environmental effects. Finally, some events are beyond the scope of this Paris-centric review,

such as the sailing events held in Marseille, and the surfing events held in Tahiti.

Furthermore, it is imperative to recognise that future summer sports events will, at some point, experience extreme environmental challenges (eg, Los Angeles 2028 Olympic and Paralympic Games will occur a few hundred miles from the hottest ever recorded temperature on earth). The experiences and lessons learnt from addressing environmental challenges at Paris 2024 can serve as valuable templates for future sporting events worldwide (as did Doha 2019 and Tokyo 2020), or guidance for the general public (eg, with the ambition to make the Seine swimmable). The comprehensive local warnings and recommendations provided to organising committees (table 2; figures 1 and 2) could offer invaluable guidance for mitigating environmental impacts in diverse locales hosting major competitions.

X Lois Mouglin @LoisMouglin, Valérie Bougault @VBougault, Sébastien Racinais @ephysiol, Margo L Mountjoy @margomountjoy, Ben Stephenson @bstephenson311, Sarah Carter @_SKCarter, Lewis J James @LJJ_nutrition, Stephen A Mears @steve_mears and Lee Taylor @DrLeeTaylor

Contributors LM, SM and LT conceptualised the article. LM and LT wrote the article, with VB, SR, MLM, BS, LJJ, SM and SC providing critical input. SC designed and created the figure, with LM and LT providing content and critical input. All authors contributed to drafting or revising the manuscript and approved the final version to be published. LT (ltaylor2@lboro.ac.uk) is the guarantor.

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ORCID iDs

Lois Mouglin <http://orcid.org/0009-0002-9401-6080>
 Valérie Bougault <http://orcid.org/0000-0002-2258-6562>
 Sébastien Racinais <http://orcid.org/0000-0003-0348-4744>
 Margo L Mountjoy <http://orcid.org/0000-0001-8604-2014>
 Ben Stephenson <http://orcid.org/0000-0003-4885-1974>
 Sarah Carter <http://orcid.org/0000-0002-9170-9001>
 Lewis J James <http://orcid.org/0000-0001-6514-5823>
 Stephen A Mears <http://orcid.org/0000-0003-3941-9426>
 Lee Taylor <http://orcid.org/0000-0002-8483-7187>

REFERENCES

- Nakamura M, Naito T, Saito T, *et al*. Case report: countermeasures against heat and Coronavirus for Japanese athletes at the Tokyo 2020 Olympics and Paralympic games. *Front Sports Act Living* 2022;4:878022.
- Sugawara M, Manabe Y, Yamasawa F, *et al*. Athlete medical services at the Marathon and race walking events during Tokyo 2020 Olympics. *Front Sports Act Living* 2022;4:872475.
- Sandford GN, Stellingwerff T, Koehle MS. Ozone pollution: a 'hidden' environmental layer for athletes preparing for the Tokyo 2020 Olympic & Paralympics. *Br J Sports Med* 2021;55:189–90.
- Zhang Y, Ai J, Bao J, *et al*. Lessons learned from the COVID-19 control strategy of the XXXII Tokyo summer Olympics and the XXIV Beijing winter Olympics. *Emerg Microbes Infect* 2022;11:1711–6.
- Yiou P, Cadiou C, Faranda D, *et al*. Ensembles of climate simulations to anticipate worst case Heatwaves during the Paris 2024 Olympics. *Npj Clim Atmos Sci* 2023;6:1–8.
- Delaplace M, Schut PO. *Hosting the Olympic Games: Uncertainty, Debates and Controversy*. Abingdon-on-Thames, Oxfordshire: Routledge, 2019:1–200.
- Ross WJ, Orr M. Predicting climate impacts to the Olympic games and FIFA men's world cups from 2022 to 2032. *Sport in Society* 2022;25:867–88.
- McKenzie DC, Boulet LP. Asthma, outdoor air quality and the Olympic games. *CMAJ* 2008;179:543–8.
- Chamberlain M, Marshall AN, Keeler S. Open water swimming: medical and water quality considerations. *Curr Sports Med Rep* 2019;18:121–8.
- Racinais S, Alonso JM, Coutts AJ, *et al*. Consensus recommendations on training and competing in the heat. *Scand J Med Sci Sports* 2015;25 Suppl 1:6–19.
- Rundell KW. Effect of air pollution on athlete health and performance. *Br J Sports Med* 2012;46:407–12.
- Harlan SL, Ruddell DM. Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Curr Opin Environ Sustain* 2011;3:126–34.
- Ibebuchi CC, Abu IO. Characterization of temperature regimes in Western Europe, as regards the summer 2022 Western European heat wave. *Clim Dyn* 2023;61:3707–20.
- Infoclimat. Available: <https://www.infoclimat.fr/climatologie/globale/paris-montsouris/07156.html>
- Masselot P, Mistry M, Vanoli J, *et al*. Excess mortality attributed to heat and cold: a health impact assessment study in 854 cities in Europe. *Lancet Planet Health* 2023;7:e271–81.
- Alkemade P, Daanen HAM, Janssen TWJ, *et al*. Heat preparedness and exertional heat illness in Paralympic athletes: a Tokyo 2020 survey. *Temperature* 2023;10:264–75.
- Racinais S, Havenith G, Aylwin P, *et al*. Association between thermal responses, medical events, performance, heat acclimation and health status in male and female elite athletes during the 2019 Doha world athletics championships. *Br J Sports Med* 2022;56:439–45.
- Griggs KE, Stephenson BT, Price MJ, *et al*. Heat-related issues and practical applications for Paralympic athletes at Tokyo 2020. *Temperature* 2020;7:37–57.
- Gibson OR, James CA, Mee JA, *et al*. Heat alleviation strategies for athletic performance: a review and practitioner guidelines. *Temperature* 2020;7:3–36.
- Brocherie F, Pascal M, Lagarrigue R, *et al*. Climate and health challenges for Paris 2024 Olympics and Paralympics. *BMJ* 2024;384:e077925.
- Schuster C, Honold J, Lauf S, *et al*. Urban heat stress: novel survey suggests health and fitness as future avenue for research and adaptation strategies. *Environ Res Lett* 2017;12:044021.
- Xu Z, FitzGerald G, Guo Y, *et al*. Impact of heatwave on mortality under different Heatwave definitions: a systematic review and meta-analysis. *Environ Int* 2016;89–90:193–203.
- Vanos JK, Kosaka E, Iida A, *et al*. Planning for spectator thermal comfort and health in the face of extreme heat: the Tokyo 2020 Olympic Marathons. *Science of The Total Environment* 2019;657:904–17.
- Racinais S, Hosokawa Y, Akama T, *et al*. IOC consensus statement on recommendations and regulations for sport events in the heat. *Br J Sports Med* 2023;57:8–25.
- McIntyre RD, Zurawlew MJ, Oliver SJ, *et al*. A comparison of heat acclimation by post-exercise hot water immersion and exercise in the heat. *J Sci Med Sport* 2021;24:729–34.
- Casadio JR, Kilding AE, Cotter JD, *et al*. From lab to real world: heat acclimation considerations for elite athletes. *Sports Med* 2017;47:1467–76.
- Tyler CJ, Reeve T, Hodges GJ, *et al*. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Med* 2016;46:1699–724.
- Galan-Lopez N, Esh CJ, Leal DV, *et al*. Heat preparation and knowledge at the world athletics race walking team championships Muscat 2022. *Int J Sports Physiol Perform* 2023;18:813–24.
- Racinais S, Périard JD. Benefits of heat re-acclimation in the lead-up to the Tokyo Olympics. *Br J Sports Med* 2020;54:945–6.
- McCleave EL, Slattery KM, Duffield R, *et al*. Temperate performance benefits after heat, but not combined heat and hypoxic training. *Med Sci Sports Exerc* 2017;49:509–17.
- Minson CT, Cotter JD. Crosstalk proposal: heat acclimatization does improve performance in a cool condition. *J Physiol* 2016;594:241–3.
- Yamazaki F. Effectiveness of exercise-heat acclimation for preventing heat illness in the workplace. *J UOEH* 2013;35:183–92.
- Taylor L, Carter S, Stellingwerff T. Cooling at Tokyo 2020: the why and how for endurance and team sport athletes. *Br J Sports Med* 2020;54:1243–5.
- Bongers CCWG, de Korte JQ, Eijssvogels T. Infographic. Keep it cool and beat the 703 heat: cooling strategies for exercise in hot and humid conditions. *Br J Sports Med* 2021;55:643–4.
- Bongers CCWG, Thijssen DHJ, Veltmeijer MTW, *et al*. Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. *Br J Sports Med* 2015;49:377–84.
- Bongers C, Hopman MTE, Eijssvogels TMH. Cooling interventions for athletes: an overview of effectiveness, physiological mechanisms, and practical considerations. *Temperature* 2017;4:60–78.
- Tyler CJ, Sunderland C, Cheung SS. The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: a meta-analysis. *Br J Sports Med* 2015;49:7–13.
- Racinais S, Ihsan M, Taylor L, *et al*. Hydration and cooling in elite athletes: relationship with performance, body mass loss and body temperatures during the Doha 2019 IAAF world athletics championships. *Br J Sports Med* 2021;55:1335–41.
- Esh CJ, Carter S, Galan-Lopez N, *et al*. A review of elite athlete evidence-based knowledge and preparation for competing in the heat. *J Sci Sport Exerc* 2024.

- 40 James LJ, Funnell MP, James RM, *et al.* Does hypohydration really impair endurance performance? Methodological considerations for interpreting hydration research. *Sports Med* 2019;49:103–14.
- 41 Galloway SDR, Maughan RJ. The effects of substrate and fluid provision on thermoregulation and metabolic responses to prolonged exercise in a hot environment. *J Sports Sci* 2000;18:339–51.
- 42 Junge N, Jørgensen R, Flouris AD, *et al.* Prolonged self-paced exercise in the heat – environmental factors affecting performance. *Temperature* 2016;3:539–48.
- 43 Schmit C, Duffield R, Hausswirth C, *et al.* Pacing adjustments associated with familiarization: heat versus temperate environments. *Int J Sports Physiol Perform* 2016;11:855–60.
- 44 Sakalidis KE, Burns J, Van Biesen D, *et al.* The impact of cognitive functions and intellectual impairment on pacing and performance in sports. *Psychol Sport Exerc* 2021;52:101840.
- 45 Vanos JK, Middel A, McKecher GR, *et al.* Hot playgrounds and children's health: a multiscale analysis of surface temperatures in Arizona, USA. *Landsc Urban Plan* 2016;146:29–42.
- 46 Nakamura S, Wada K, Yanagisawa N, *et al.* Health risks and precautions for visitors to the Tokyo 2020 Olympic and Paralympic games. *Travel Med Infect Dis* 2018;22:3–7.
- 47 Kenny GP, Yardley J, Brown C, *et al.* Heat stress in older individuals and patients with common chronic diseases. *CMAJ* 2010;182:1053–60.
- 48 Zhang J-J, Wang L-D, Chen Z, *et al.* Medical care delivery at the Beijing 2008 Olympic games. *World J Emerg Med* 2011;2:267–71.
- 49 Hosokawa Y, Racinais S, Akama T, *et al.* Prehospital management of Exertional heat stroke at sports Competitions: International Olympic committee adverse weather impact expert working group for the Olympic games Tokyo 2020. *Br J Sports Med* 2021;55:1405–10.
- 50 Liu L, Ogunc A. Beijing blue: impact of the 2008 Olympic games and 2014 APEC summit on air quality. *Atl Econ J* 2023;51:83–100.
- 51 Airparif. Air quality in the Paris region 2022, Available: <https://www.airparif.fr/bilan/2023/bilan-qualite-de-lair-paris-2022>
- 52 Zoran MA, Savastru RS, Savastru DM, *et al.* Peculiar weather patterns effects on air pollution and COVID-19 spread in Tokyo metropolis. *Environ Res* 2023;228:115907.
- 53 Menut L, Cholakian A, Siour G, *et al.* Impact of Landes forest fires on air quality in France during the 2022 summer. *Atmos Chem Phys* 2023;23:7281–96.
- 54 Kassens-Noor E. Transport legacy of the Olympic games, 1992–2012. *J Urban Aff* 2013;35:393–416.
- 55 Cieniewicz J, Jaspers I. Air pollution and respiratory viral infection. *Inhal Toxicol* 2007;19:1135–46.
- 56 Nazar W, Niedoszytko M. Air pollution in Poland: A 2022 narrative review with focus on respiratory diseases. *IJERPH* 2022;19:895.
- 57 Montone RA, Rinaldi R, Bonanni A, *et al.* Impact of air pollution on ischemic heart disease: evidence, mechanisms, clinical perspectives. *Atherosclerosis* 2023;366:22–31.
- 58 Hung A, Nelson H, Koehle MS. The acute effects of exercising in air pollution: a systematic review of randomized controlled trials. *Sports Med* 2022;52:139–64.
- 59 Adams WC. Effects of ozone exposure at ambient air pollution episode levels on exercise performance. *Sports Med* 1987;4:395–424.
- 60 Rundell KW, Caviston R. Ultrafine and fine particulate matter inhalation decreases exercise performance in healthy subjects. *J Strength Cond Res* 2008;22:2–5.
- 61 Carlisle AJ, Sharp NCC. Exercise and outdoor ambient air pollution. *Br J Sports Med* 2001;35:214–22.
- 62 Giles LV, Koehle MS. The health effects of exercising in air pollution. *Sports Med* 2014;44:223–49.
- 63 Price OJ, Sewry N, Schwelonus M, *et al.* Prevalence of lower airway dysfunction in athletes: a systematic review and meta-analysis by a subgroup of the IOC consensus group on 'acute respiratory illness in the athlete' *Br J Sports Med* 2022;56:213–22.
- 64 Rundell KW, Smoliga JM, Bougault V. Exercise-induced bronchoconstriction and the air we breathe. *Immunol Allergy Clin North Am* 2018;38:183–204.
- 65 Schwelonus M, Adami PE, Bougault V, *et al.* International Olympic Committee (IOC) consensus statement on acute respiratory illness in athletes part 1: acute respiratory infections. *Br J Sports Med* 2022;56:1066–88.
- 66 WHO. Public health for mass gatherings: key considerations. 2015. Available: <https://www.who.int/publications/i/item/public-health-for-mass-gatherings-key-considerations>
- 67 Simpson RJ, Campbell JP, Gleeson M, *et al.* Can exercise affect immune function to increase susceptibility to infection. *Exerc Immunol Rev* 2020;26:8–22.
- 68 Hung A, Koch S, Bougault V, *et al.* Personal strategies to mitigate the effects of air pollution exposure during sport and exercise: a narrative review and position statement by the Canadian Academy of sport and exercise medicine and the Canadian society for exercise physiology. *Br J Sports Med* 2023;57:193–202.
- 69 Pacitto A, Amato F, Salmatoniadis A, *et al.* Effectiveness of commercial face masks to reduce personal PM exposure. *Sci Total Environ* 2019;650:1582–90.
- 70 Morris NB, Pihl JF, Christiansen L, *et al.* Prolonged facemask use in the heat worsens dyspnea without compromising motor-cognitive performance. *Temperature* 2021;8:160–5.
- 71 Mullins JT. Ambient air pollution and human performance: contemporaneous and acclimatization effects of ozone exposure on athletic performance. *Health Econ* 2018;27:1189–200.
- 72 Gong H Jr, McManus MS, Linn WS. Attenuated response to repeated daily ozone exposures in asthmatic subjects. *Arch Environ Health* 1997;52:34–41.
- 73 Gangwar RS, Bevan GH, Palanivel R, *et al.* Oxidative stress pathways of air pollution mediated toxicity: recent insights. *Redox Biol* 2020;34:101545.
- 74 FranceTVinfo. Available: https://www.franceinfo.fr/les-jeux-olympiques/paris-2024/enquete-franceinfo-paris-2024-pollution-trop-elevee-normes-non-respectees-ce-que-revelent-les-analyses-de-la-qualite-de-l-eau-de-la-seine_6173826.html
- 75 Staggemeier R, Heck TMS, Demoliner M, *et al.* Enteric viruses and adenovirus diversity in waters from 2016 Olympic venues. *Sci Total Environ* 2017;586:304–12.
- 76 Mouchel J, Lucas F, Moulin L, *et al.* Bathing activities and microbiological river water quality in the Paris area: a long-term perspective. In: *The Handbook of Environmental Chemistry*. 2020.
- 77 Hall V, Taye A, Walsh B, *et al.* A large outbreak of gastrointestinal illness at an open-water swimming event in the river Thames, London. *Epidemiol Infect* 2017;145:1246–55.
- 78 Prüss A. Review of Epidemiological studies on health effects from exposure to recreational water. *Int J Epidemiol* 1998;27:1–9.
- 79 Medema GJ, van Asperen IA, Havelaar AH. Assessment of the exposure of swimmers to Microbiological Contaminants in fresh waters. *Water Sci Technol* 1997;35:157–63.
- 80 Rivière A, Ladet D, Thomas W, *et al.* *Projections Des Températures de l'eau de La Seine à Paris à l'horizon 2100*. PIREN. Mines Paris-PSL, 2021.
- 81 Macaluso F, Barone R, Isaacs AW, *et al.* Heat stroke risk for open-water swimmers during long-distance events. *Wilderness Environ Med* 2013;24:362–5.
- 82 Stellingwerff T, Pyne DB, Burke LM. Nutrition considerations in special environments for aquatic sports. *Int J Sport Nutr Exerc Metab* 2014;24:470–9.
- 83 France24. Available: <https://www.france24.com/en/tv-shows/down-to-earth/20230602-olympic-cleanup-swimming-in-the-seine>