
RINGS OF
FIRE
HOW HEAT COULD IMPACT THE
2021 TOKYO OLYMPICS
火の五輪
東京2021オリンピックへの暑熱の影響

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British Association for Sustainable Sport

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FOREWORD

BY MARA YAMAUCHI,
FORMER BRITISH OLYMPIC MARATHON RUNNER

As the world continues to grapple with the COVID pandemic, the forthcoming Tokyo Olympic Games are a highlight that we can all look forward to. The Olympics is the pinnacle of achievement in many sports, and competing in them is the dream of many youngsters. Having lived, trained and competed in Japan as an elite athlete, I saw how much Japanese people love their sport. I feel sure that, despite the pandemic, Japan will deliver a spectacle with flawless organisation, characteristically warm hospitality, and unrivalled sporting theatre.

Yet sport, like all the activities we humans do on Earth, is increasingly affected by climate change. Rising temperatures have an obvious effect on outdoor sports, not only on the athletes but on officials, broadcasters and spectators too. Extreme weather events occurring more frequently might lead to more major sporting events being disrupted or cancelled. And the impact of climate change on the natural environments where sports events take place, could also have far-reaching effects.

My own event, the marathon, being an outdoor endurance event, is especially vulnerable to what climate change might bring in the years to come. I sincerely hope that future generations of athletes will be able to compete safely in an Olympic marathon, as I was fortunate enough to do. But more and more, heat acclimatisation will become essential, not just desirable for all marathon runners competing in hot environments.

Nothing stirs up passion, motivation and fascination quite like sport. In one way or another, most of us love it. But we risk potentially far-reaching consequences for sport as we know it if climate change continues apace. We can all do our bit, even in a small way, to mitigate the effects of climate change, and conserve sport and the Olympics in viable forms for future generations.

FOREWORD

マーラ・ヤマウチ (オリンピックマラソン元イギリス代表選手)

パンデミックの収束に向けて世界が新型コロナウイルスとの戦いを続ける中、まもなく開催される東京五輪は皆が楽しみにできるハイライトです。数々のスポーツにおいてオリンピックは世界最高峰の大会であり、多くの若手選手がオリンピック出場を夢見ています。

私はかつてエリート選手として日本で生活し、トレーニングし、また競技に出場し、日本の皆さんがどれほどスポーツを愛好されているかを存じておりました。日本は、申し分のない組織と独特の温かなおもてなし、そして最高の競技舞台でもって、パンデミックにもかかわらず素晴らしい祭典をもたらしてくれることと確信しております。

しかしながらスポーツは、私たち人類が地球上で行う全ての活動がそうであるように、気候変動の影響をますます受けています。気温の上昇が屋外で行われるスポーツに対して、それもアスリートだけでなく、競技役員や放送局、観客にも影響を与えることは明らかです。

異常気象の発生頻度が高まることで、中断あるいは中止に追いやられる主要大会が増えるかもしれません。また、気候変動が大会開催地の自然環境に及ぼす影響は計り知れないものがあります。

私自身の競技であるマラソンは屋外における耐久競技であることから、気候変動がこの先数年間にもたらし得る事態にとりわけ脆弱です。幸運にも私がそうできたように、将来世代の選手がオリンピックマラソン競技に安全に出場できることを心から願っております。しかし、暑い環境で競技するすべてのマラソン選手にとって、暑熱順化はただ望ましいというだけでなく、次第に必須となることでしょう。

スポーツのように情熱、モチベーション、興味を掻き立てるものはなかなかありません。私たちの多くは何かしらの形でスポーツを愛好しています。ただ、このまま気候変動が加速し続ければ、スポーツに多大な影響が及ぶ恐れがあることは周知の通りです。気候変動の影響を緩和し、スポーツ、そしてオリンピックを実行可能な形で将来世代に残していくために、たとえささやかでも私たち一人一人が役割を担うことができます。

FOREWORD

BY RUSSELL SEYMOUR

Sport is exposed to climate change. Our challenge has been to calculate the risk and prepare the right response. In the absence of a concerted effort from governments to help sport think this through, BASIS has taken on that challenge. Rings of Fire builds on the Hit for Six and Game Changer reports to add to the body of robust science-based evidence about the impacts of climate change on the sports we love.

The message is clear – the number of situations in which we are exposing athletes and competitors to extreme risk, at all levels of sport, continues to grow as climate change intensifies.

Athletes testing themselves at the highest levels of human capacity are being asked to compete in environments that are becoming too hostile to human physiology. Our love and appetite for sport risks straying into brutality. Athletes can race against time and each other, but they cannot be expected to outrun climate change.

This report is the clearest analysis of the way in which climate change could impact the Tokyo Olympics, and includes hard-hitting analysis of the way crown-jewel events in sports followed and played by millions around the world – such as the Australian Open tennis championships – are already in the cross-hairs of global warming. We need to heed these warnings.

We also need to take the recommendations seriously. They are sober and sensible, based on both climate science and thermal physiology. Combined with the BASIS Action Plan for sustainable sport – One Health, One World, One Team – to be published in the summer 2021 – they help to insulate athletes against the worst impacts of climate change and enable sport to become part of the solution to humanity's greatest challenge.

The risk and cost to athletes and sporting institutions outlined in this report is an expression of the wider threat climate change poses to all of us. The science is clear, and the real-world impacts – worsening extremes of heat, drought, storms and flooding, and unprecedented levels of pollution – are increasingly the lived experience for millions. Climate change is with us and, without deep and urgent action, it will get much worse. Even the deniers no longer deny it.

Dr Russell Seymour is Founder and Chief Executive of BASIS (the British Association for Sustainable Sport).

ラッセル・シーモア（英国持続可能なスポーツ振興協会（BASIS）CEO）

スポーツは、気候変動の脅威にさらされています。そのリスクを見積もり、適切な対応策を準備することが我々の課題となっています。スポーツ界がこれを熟慮するよう力添えをするための各国政府による協調的な取り組みがないことから、BASIS（British Association for Sustainable Sport：英国持続可能なスポーツ振興協会）はその課題を引き受けました。「火の五輪（Rings of Fire）」は、「ヒットフォーシックス（Hit for Six）」および「ゲームチェンジャー（Game Changer）」報告書をもとに、気候変動が我々の愛好するスポーツに与える影響について科学的根拠に基づく強力なエビデンスの追加報告を行うものです。

そのメッセージは明白です。気候変動が激化する中、スポーツのあらゆるレベルにおいて、アスリートや競技者が非常な危険にさらされる局面は増え続けています。

人間の能力の極限に挑むアスリートは、生理学的に厳しくなりすぎている環境で競技することを求められています。我々のスポーツに対する愛情と欲求は、本来の目的を見失い残酷に陥る恐れがあります。アスリートは時間と闘い、互いに張り合うことができます。しかし、彼らに気候変動を凌ぐよう求めるわけにはいきません。

本報告書は、気候変動が東京オリンピックに与え得る影響を明快に分析するものであり、世界中で何百万人もの人々がフォローし、出場する選手権大会（全豪オープンテニスなど）をすでに直撃している地球温暖化の影響に関する辛辣な分析も含んでいます。我々はこれらの警告に耳を傾ける必要があります。

我々はまた、そうした勧告を真剣に受け止める必要があります。勧告は気候科学および温熱生理学に基づくものであり、実用的かつ理にかなっています。2021年夏に発表予定の持続可能なスポーツのためのBASIS行動計画「ワンヘルス（One Health）、ワンワールド（One World）、ワンチーム（One Team）」と合わせて、気候変動の最悪の影響からアスリートを守り、スポーツに人類最大の課題の解決の一端を担う機会を与えてくれることでしょう。

本報告書で概説されるアスリートおよびスポーツ組織に降りかかるリスクと負担は、我々全員に及ぶ気候変動の広範な脅威を表面化しています。科学は明確であり、猛暑や水不足、暴風雨、洪水の悪化、そして前例のないレベルの大気汚染といった実社会への影響をさらに大勢の人が身をもって感じています。気候変動は我々と共にあり、早急かつ抜本的な対応がなければ、一層悪化します。気候変動の否定論者ですら、もはや否定しないでしょう。

2 - EXECUTIVE SUMMARY

In July 2018 a deadly heat wave struck Japan, with 40°C temperatures leaving over 1,000 dead and 22,000 in hospital with heatstroke. Heat waves hit again in the summers of 2019 and 2020, leaving thousands in hospital as temperatures across the country topped 39°C.

The mean annual temperature in Tokyo, the capital city and host of the 2021 Olympics, has increased by 2.86°C since 1900, more than three times as fast as the world's average. Since the 1990s Tokyo residents have frequently experienced more days when the maximum daily temperature exceeds 35°C.

Multiple factors can lead to intense heat and high levels of humidity, but the 2018 heat wave "could not have happened" without climate change say scientists. As Olympic stars, their coaches and heat experts explain in this report, intense heat and high levels of humidity are a threat to athletes at the 2021 Tokyo Olympics.

This study hears from leading triathletes, rowers, tennis players, marathon runners and scientists advising athletes how to cope in extreme conditions. All love their sports and are passionate about the Olympics. Yet all voice fears that climate impacts will affect their health and performance in Tokyo this summer.

Ben Bright, head coach at the British Triathlon Federation, tells us conditions at the 2019 Tokyo test event were so extreme the running leg was cut short and swim cancelled for para-athletes. "The difference of 1-2 degrees on a race day will have a major impact on whether the event is safe to run," he says.

GB hopeful Melissa Wilson explains how life on the water is now on the frontline of heat impacts. Three rowers required medical treatment after the 2019 Tokyo trials. "I think we're certainly approaching a danger-zone… it's a horrible moment when you see athletes cross the line, their bodies fling back in total exhaustion, and then not rise up," she tells us.

South Africa's former world No.5 tennis player Kevin Anderson details how players on Tour are increasingly aware of heat and humidity, changing training and nutrition intake as well as on-court tactics to cope. Eighteen-time Grand Slam winner Novak Djokovic has asked authorities to take heat into account when scheduling matches in Tokyo.

Makoto Yokohari, an advisor to the Tokyo Organising Committee for the Olympic and Paralympic Games, says high levels of summer heat and humidity could be a 'nightmare'[1]. The marathon has been shifted to Sapporo while road cycling will take place in the cooler climes of Mount Fuji. Yet there are limits to adaptation – even races run at night such as the women's marathon at the 2019 World Athletics Championships in Doha can leave runners in hospital.

This is not simply about the 2021 Tokyo Summer Games: rather this is a story about the future of one of the world's greatest events. Our understanding that climate change poses a threat to human society is almost exactly as old as the Olympic movement itself. In 1896 Svante Arrhenius started modern climate science, predicting burning coal would warm the Earth.

Humanity's pursuit of fossil fuels and its consequences match the Olympic motto: Faster, Higher, Stronger. Since the turn of the last century average global temperatures have risen by over 1°C, with a globally agreed safe limit of 1.5°C now at risk. Should that be breached, scientists warn of more powerful and wetter storms; hotter, longer and more frequent heatwaves; worse droughts; increased wildfires and sea-level rise.

Olympics organisers have made their best efforts to dodge the COVID-19 pandemic by delaying the Games for a year. No such option is available for climate change: cumulative emissions are such that the 2021 Games and those in the future will inevitably be impacted, with resulting safety concerns for athletes, spectators and media.

Lewis Hamilton, Shane Warne, Paula Radcliffe and Mo Farah are amongst the global sports stars voicing concern about the threat of climate change. The Olympics and broader sporting community needs to do its bit to cut global levels of pollution – if it does not, its long-term future is at stake. As double Olympic champion Alastair Brownlee tells us: "Athletes' health is endangered by competing in extreme heat and humidity… It's a concern for everyone."

要旨

2018年7月、命にかかわる危険な熱波が日本を襲い、気温は40℃に達し、熱中症による死亡者数は1,000人、入院患者数は2万2000人を超えた。2019年、2020年にも再び熱波が襲い、日本各地の気温は39℃を超え数千人が入院に至った。

2021オリンピックの開催地である首都・東京の年平均気温は、1900年から2.86℃上昇しており、世界平均の3倍以上の速度で気温上昇が進んでいる。1990年代以降、東京では日最高気温が35℃を上回る日がより頻繁に生じている。

猛暑と高湿度を引き起こす要因は複数あるが、科学者によれば、2018年の熱波は気候変動の影響なくして「起こり得なかった」という。本報告書にてオリンピック選手、監督、および専門家が説明するように、東京2021オリンピックでは猛暑と高湿度は選手にとって脅威となっている。

本調査は、トライアスロン、ボート、テニス、マラソンのトップ選手のほか、選手に対し過酷な天候下における対処法について助言を行う科学者にヒアリングを行うものである。いずれの人物もスポーツ愛好家であり、オリンピックに情熱を注いでいる。だが、来たる7月の東京では、気候が選手のパフォーマンスおよび健康に影響を及ぼすことになるのではないかと一様に危惧している。

英国トライアスロン連盟のベン・ブライト監督によれば、2019年の東京でのテストイベントでは、異常気象によりラン競技の距離が短縮され、パラのスイムが中止になったという。ブライト監督は、「レース当日の1、2度の（気温）差が大会を安全に運営できるかどうかを大きく左右する」と述べた。

英国の有望選手メリッサ・ウィルソンは、水上での競技がいかに暑熱の影響を直に受けているかについて説明する。2019年の東京でのテストイベントの後、３名のボート選手が医療処置を受けた。「私たちは間違いなく危険地帯に近づいていると思う。（中略）選手が限界を超え、完全に疲れ果てて戻ってきて、その後、立ち上がれない姿を見るのは恐ろしい瞬間」とウィルソン選手は語った。

元世界ランキング5位のテニス選手である南アフリカのケビン・アンダーソンは、遠征中の選手たちが高温多湿をますます実感し、トレーニングや栄養摂取量、戦術を変えていることについて詳しく述べた。また、グランドスラムを18度優勝しているノバク・ジョコビッチは、東京での競技スケジュールを設定する際には、暑熱を考慮するよう関係当局に求めている。

東京オリンピック・パラリンピック組織委員会委員の横張真氏は、夏の高温多湿は「悪夢」になりかねないと述べている。マラソンは札幌に変更され、自転車ロードレースはより涼しい気候の富士山麓で開催されることになった。とはいえ、気候変動適応には限界があり、例えば2019世界陸上ドーハの女子マラソンのように夜間に開催するレースであっても、救急搬送される選手が出る可能性がある。

これは2021東京夏季オリンピックだけを取り立てるものではなく、世界屈指のスポーツ大会の未来について語るものである。気候変動が人間社会を脅かすという我々の認識は、近代オリンピックの誕生と同時期にまで遡る。1896年、スヴァンテ・アレニウスは現代の気候科学を世界で初めて論じ、石炭の燃焼によって地球の温暖化が起こると予想した。

人類の化石燃料追求とその成り行きは、「より速く、より高く、より強く」というオリンピックのモットーと一致する。20世紀への変わり目から地球の平均気温は１℃以上高くなっており、現在、世界的に合意された1.5℃という安全圏に留められない危険性がある。それを越えることになれば、より強力かつ降水量の多い暴風雨を引き起こし、より暑く長期化する熱波がさらに頻繁に生じるとともに、干ばつの悪化、森林火災の増加、さらには海面上昇につながると科学者は警告している。

オリンピック主催者は、開催を1年延期することで、新型コロナウイルスのパンデミックによる中止を回避するために最善を尽くした。だが、気候変動に関してはそのような選択肢はない。累積する二酸化炭素の排出量が2021東京五輪や今後の大会に影響を及ぼすことは必至であり、選手や観客、報道陣の安全が懸念されている。

ルイス・ハミルトン、シェーン・ウォーン、ポーラ・ラドクリフ、モー・ファラーなどといった世界的スター選手が気候変動の脅威について懸念を表明している。オリンピック、そして広くスポーツ界としても世界の大気汚染レベルの引き下げに寄与する必要があり、さもなければ、遠い将来の開催は危うい。オリンピックで金メダルを2度獲得しているアリスター・ブラウンリーは、「極度の高温多湿下での競技によって選手の健康が脅かされている。（中略）それは皆にとって懸念材料だ」と語った。

SECTION 3:

TOKYO 2021 OLYMPICS & CLIMATE CHANGE - THE SCIENCE

BY PALOMA TRASCASA CASTRO,
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Since preindustrial times, the temperature of the Earth has already risen by 1.1°C. To some, this might not seem like much. The reality is, however, that every increase in temperature by a tenth of a degree makes some areas of the planet more and more difficult to inhabit. Increasing concentrations of carbon dioxide (CO_2) due to human activities contribute to the greenhouse gas effect, which is the key driver behind the trend in rising global temperatures. The world has already experienced an unprecedented wave of unpredictable weather events, such as extreme temperature, droughts and floods, which scientists have attributed to human activities [2].

Climate change does not affect every region of the world homogeneously. According to the Climate Change Monitoring Report from the Japanese Meteorological Agency (JMA), Japan and more specifically Tokyo, is warming much faster than the rest of the planet. The mean and maximum daily temperature over Japan have increased, but the largest temperature rise is in the minimum temperature values, especially during the winter months [3]. This translates in less snow depth every winter, especially over Western Japan where the snow layer is 12.3% thinner each decade.

The mean annual temperature in Tokyo, the capital city and host of the 2021 Olympics, has increased by 2.86°C since 1900 (see Figure 1). This is more than three times as fast as the world's average. On top of the global and Japanese trends, changes in land use and urbanisation in Tokyo enhance the urban heat island effect (UHI), which traps heat in the surface and impacts on thermoregulation, effectively impairing a city's ability to breathe.

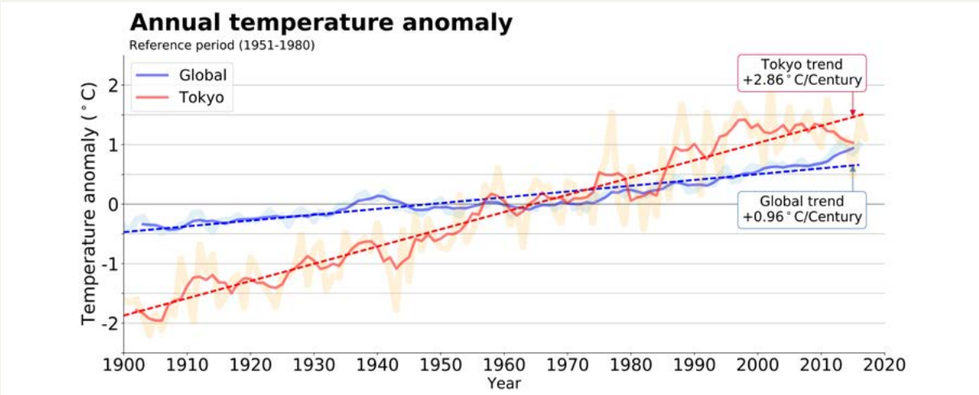

Fig. 1: Observed annual temperature anomalies from 1900 to 2019 for the globe (solid blue) and Tokyo (solid red). The reference period used as a baseline to calculate the anomalies is 1951-1980. The light lines in the back are the original values, the strong solid lines indicate the five-year running mean and the dashed lines show the linear trend of the time series. Global temperature anomalies are obtained from the NASA GISS Surface Temperature Analysis (GISTEMP v4) and the observed temperature values over Tokyo is obtained from the JMA Automated Meteorological Data Acquisition System (AMeDAS) station in Tokyo.

Since the late nineteenth century, extremely high temperature events in Tokyo have become more frequent. Each year has more days when the maximum daily temperature exceeds 35°C, especially since the 1990s.

Night-time temperatures have also risen significantly. Tropical nights, when temperatures do not fall below 20°C, are twice as frequent today as in the 1880s. Due to the UHI effect, during the night the surface of the largely urbanised Tokyo area releases the heat that has been trapped for the duration of the day, preventing the city from cooling. A typical year in Tokyo now has 27 additional tropical nights, compared to a century ago. Analysing the positive trends (Figure 2), we would expect even higher daily temperatures as a result of increasing global levels of carbon dioxide in the atmosphere.

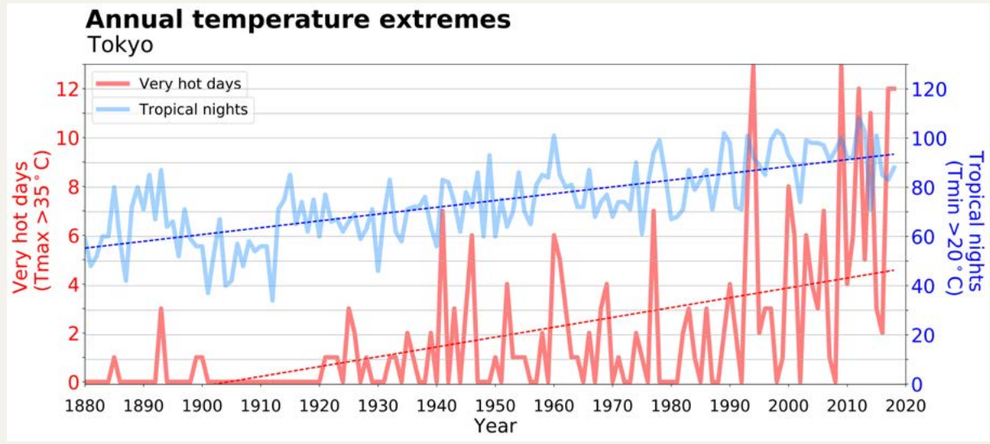

Fig.2 Annual number of very hot days (red) and tropical nights (blue) in Tokyo from 1880 to 2019. Very hot days are defined as days when the maximum daily temperature exceeds 35°C. Tropical nights account for days when the minimum daily temperature exceeds 20°C. The dashed lines indicate the linear trend associated with each time series.

BUT WHAT IS DRIVING THE INCREASE IN TEMPERATURE?

Attribution to heat waves

The decade from 2010 to 2020 has been marked by a series of unprecedented hot years. In the summer of 2013, 143 sites in Japan experienced maximum temperatures that were 1.2°C warmer than the average summer temperature [4]. Two years later, temperatures exceeded 35°C for 8 consecutive days, causing 10,000 cases of heatstroke. The anomalous heat conditions over Japan in 2015 were unexpected since the country was under the cooling influence of the El Niño phenomenon. A 2016 study into those conditions confirmed that warming caused by human activity made it approximately 1.6 times more probable that such a heat wave would occur [5].

In 2018, a record-breaking summer heat wave hit Japan. A study led by Japanese academics states that this event would not have happened without global warming caused by humans [6]. Prolonged dry and hot conditions favoured by a strong high-pressure system precipitated what was to become one of the most severe heat waves in the history of Japan. More than 1,000 people lost their lives and over 32 million people were exposed to the heat wave.

Those aged 65 years and older are particularly vulnerable to climate change, especially during heat waves. This is particularly significant in Japan, where 28.4% of the population is over 65. On a worldwide level, the number of heat waves affecting older populations has reached unprecedented levels [7].

The Intergovernmental Panel on Climate Change report on Climate Extremes suggested in 2012 that days of extreme heat that used to occur once every 20 years will occur every other year by the end of the twenty-first century [8].

Heat waves are part of the natural variability of the climate system. However, human influence in the climate system can amplify their strength and frequency, multiplying the associated risks on ecosystems and populations. It is very likely that extremely hot temperatures in Japan will become the new normality if the world's temperature increases by up to 1.5°C above preindustrial levels.

SECTION 4:

THE UBIQUITOUS CHALLENGE OF HEAT- A SUMMARY

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In a sporting context, a hot and/or humid environment can represent a risk to the performance and health of spectators, officials and athletes. From sunburn, through cognitive impairment, to heat exhaustion or collapse from heat stroke, all facets of a sporting event- and all those involved- can be adversely affected. Climate change will increase average environmental temperatures- more importantly for the sporting community, the number of extreme weather events will increase, including heat waves, with consequent impacts on those involved with sport.

Humans perform continuous exercise best in cool, dry environments at around 11°C. As environmental temperature and/or humidity increase, both cognitive and physical performance deteriorate, to the point where health is put at risk (Figure 1).

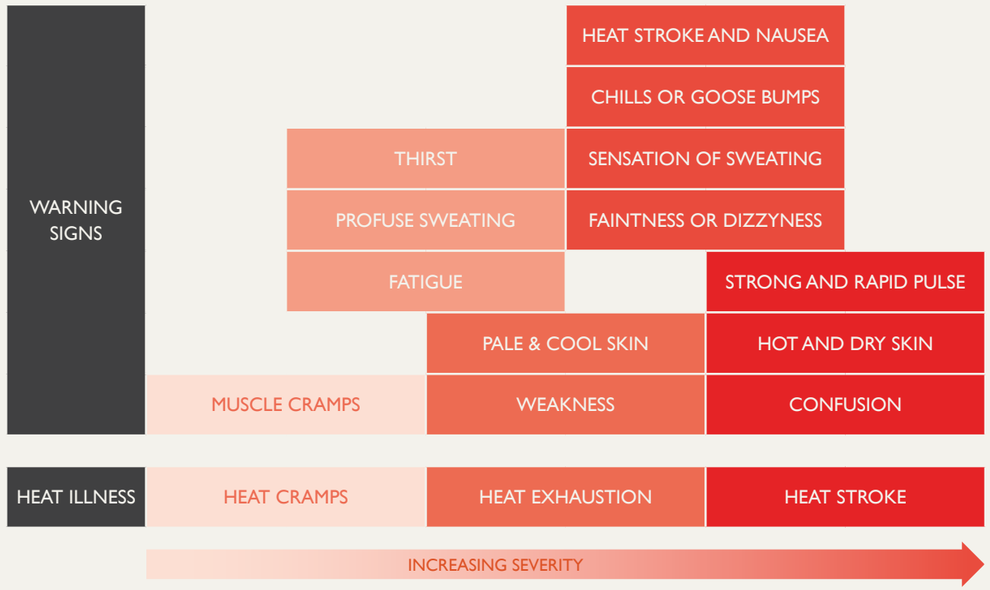


Figure 1. The impact of heat on performance and health.

COGNITIVE

Increases in body temperature can negatively affect cognitive tasks, especially complex tasks such as vigilance (the ability to maintain attention), short-term/working memory and dual tasks – all of which are important in sporting performance by both athletes and officials. Heat stress also adversely affects comfort, mood state, vigour and fatigue. The perception of feeling hot, or the body's responses associated with heat, such as sweating, can be distracting, affect concentration and thereby performance in sports and officiating where focus and attention are required.

PHYSICAL

Overheating can compromise muscle, cardiovascular and cognitive function. This compromise is compounded by associated dehydration. These responses impair physical performance. If heating continues unabated heat stroke results; this is a serious medical condition with long term, multi-organ, consequences [9]. For the spectator, the combination of overheating and sunburn represent potential threats.

The threat of heat on health and performance necessitates the introduction of mitigation strategies that include: scheduling events to cooler times of the day/year; introduction of "cooling breaks" into events; acclimatisation strategies; cooling and rehydration innovations; adjustments to selection polices; alterations in game/race strategy; clothing innovations.

With climate change, and an associated ever greater number of extreme weather conditions, the likelihood of a sporting event taking place in a hot/humid environment increases. Even if the health of those involved is not threatened (and it is quite possible that it will be), the overall experience will be diminished by uncomfortable conditions for spectators and impaired performance by athletes and officials. The expectations of all involved in some sporting events will need to be adjusted.

HOW HOT IS TOO HOT?

The most widely used measure of hot environments is the "Wet Bulb Globe Temperature" (WBGT) index; it is regarded by many as the criterion standard for the assessment of thermal stress during physical activity. The index combines dry (Tdb) and wet bulb (Twb) air temperature[10] with radiant (Tg e.g. sunlight) temperature in the following formula:

WBGT = 0.1Tdb + 0.7Twb + 0.2Tg

The high weighting for 'wet bulb' (which relates to the humidity [water vapour pressure] in the environment) emphasises the large impact humidity has on the body's ability to evaporate sweat and the importance of sweating in avoiding heat stress.

A few examples should help demonstrate why measuring WBGT is more important than measuring just air temperature. Taking a fixed air temperature of 30°C and wind speed of 0.5 metres per second in all cases:

Example 1:
Cloudy day (no sun), relative humidity 50 percent,
WBGT = 25.9°C

Example 2:
Sunny day, relative humidity 35 percent,
WBGT = 29.5°C

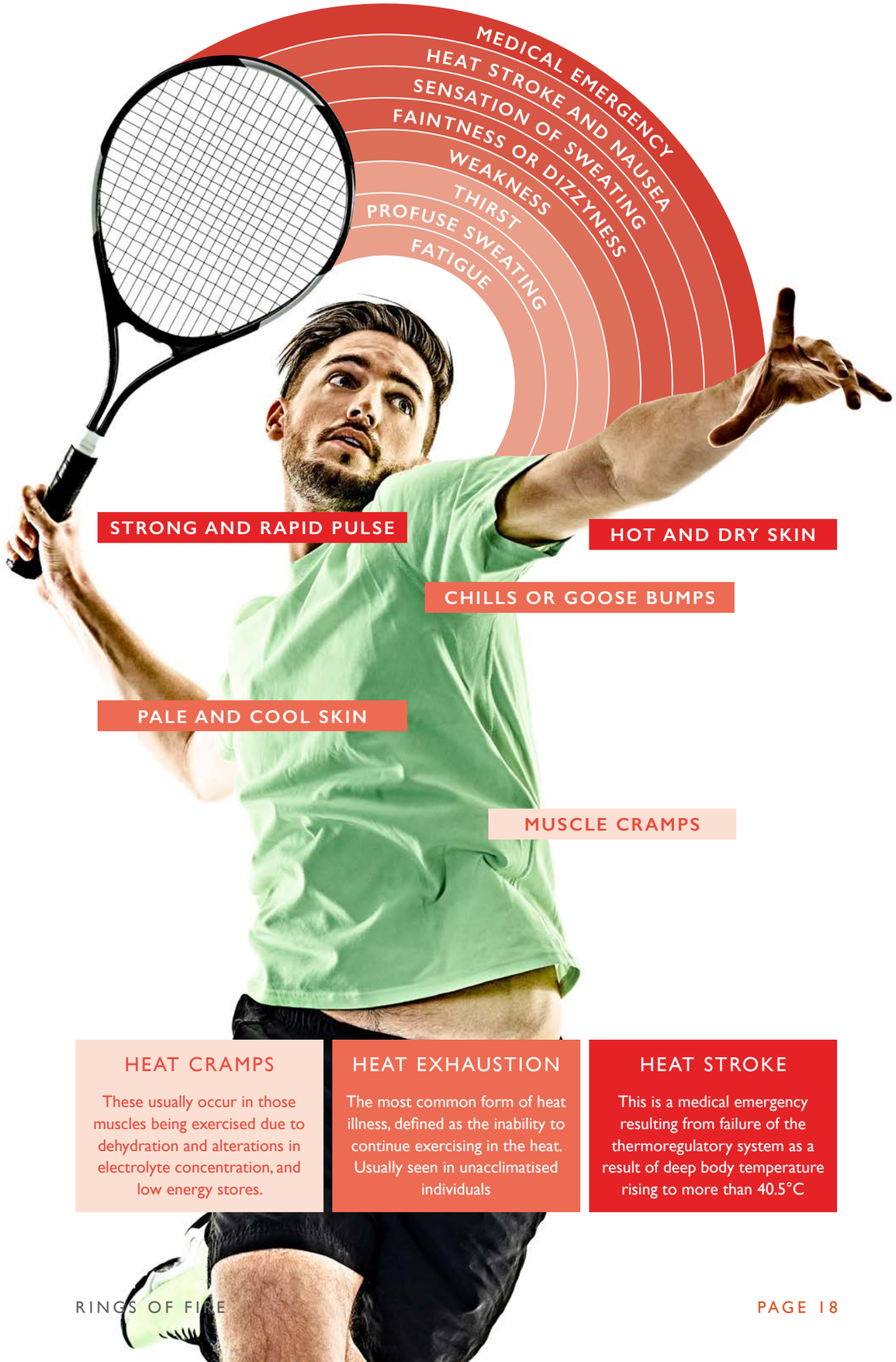
Example 3:
Light cloud cover, humid day (relative humidity 90 percent),
WBGT = 32.0°C

These examples demonstrate that WBGT does not equal air temperature - they are different measurements; while air temperature alone provides relatively little information about the potential heat strain faced by athletes [11]. They also emphasise that high humidity limits sweat evaporation and therefore the ability to control body temperature (sweating serves no function [other than dehydrating] unless the sweat produced can evaporate).

But how can WBGT be used? The American College of Sports Medicine has developed the following WBGT recommendations for avoiding heat-related injury during continuous activities such as running and cycling.

WBGT	ACTION
>28° C	BLACK FLAG: CANCEL OR RECOMMEND VOLUNTARY WITHDRAWAL. (RACES THAT ARE ALWAYS HELD IN THESE CONDITIONS SHOULD ACKNOWLEDGE THE EXTREME HEAT RISK TO THE POORLY ACCLIMATED AND NON-RESIDENT COMPETITORS IN THE PRE-RACE LITERATURE AND THE PRE-RACE ANNOUNCEMENTS)
23° C – 28°C	RED FLAG: RECOMMEND PARTICIPANTS AT INCREASED RISK FOR HEAT COLLAPSE WITHDRAW FROM RACE AND OTHERS SLOW PACE TO MATCH CONDITIONS.
18° C – 22°C	YELLOW FLAG: RECOMMEND PARTICIPANTS AT INCREASED RISK FOR HEAT COLLAPSE SLOW PACE. WARN ENTRANTS OF INCREASED RISK OF HEAT COLLAPSE.
<18°C	GREEN FLAG: COLLAPSE CAN STILL OCCUR. DECREASED RISK OF HYPERTHERMIC AND HYPOTHERMIC COLLAPSE.
<10°C	WHITE FLAG: INCREASED RISK OF HYPOTHERMIC COLLAPSE

Table 1. The American College of Sports Medicine WBGT recommendations for continuous activities



SECTION 5:
POTENTIAL HEAT IMPACT ON EVENTS

SPORT	POTENTIAL HEAT IMPACT ON EVENT	EXAMPLES OF MEASURES TO LIMIT IMPACT
TENNIS	DISRUPTION OF PLAY	ADDITIONAL COOLING BREAKS
ROAD CYCLING	SOFTENED TARMAC THAT CAN LEAD TO CRASHES; LONG PERIODS OF TIME EXPOSED TO RADIANT LIGHT	ROAD SECTIONS SPRAYED WITH WATER PRE-EVENT; RE-DESIGNED CYCLING SUITS TO REDUCE HEAT ABSORPTION AND MAXIMISE EVAPORATIVE HEAT LOSS
RACE WALK	ATHLETES UNABLE TO FINISH DUE TO HEAT STRAIN	REARRANGED HOST VENUE
EQUESTRIAN	HIGH FATIGUE LEVELS FOR THE HORSES	HORSE COOLING TENT WITH MISTED FAN AND ICE WATER
SAILING	DISCOMFORT FOR SPECTATORS AND STAFF	MORE SHADED PREPARATION AREAS FOR ATHLETES
TRIATHLON	SLOWER PERFORMANCE TIMES	AN EARLIER START

SECTION 6:

HEAT & THE PARALYMPICS

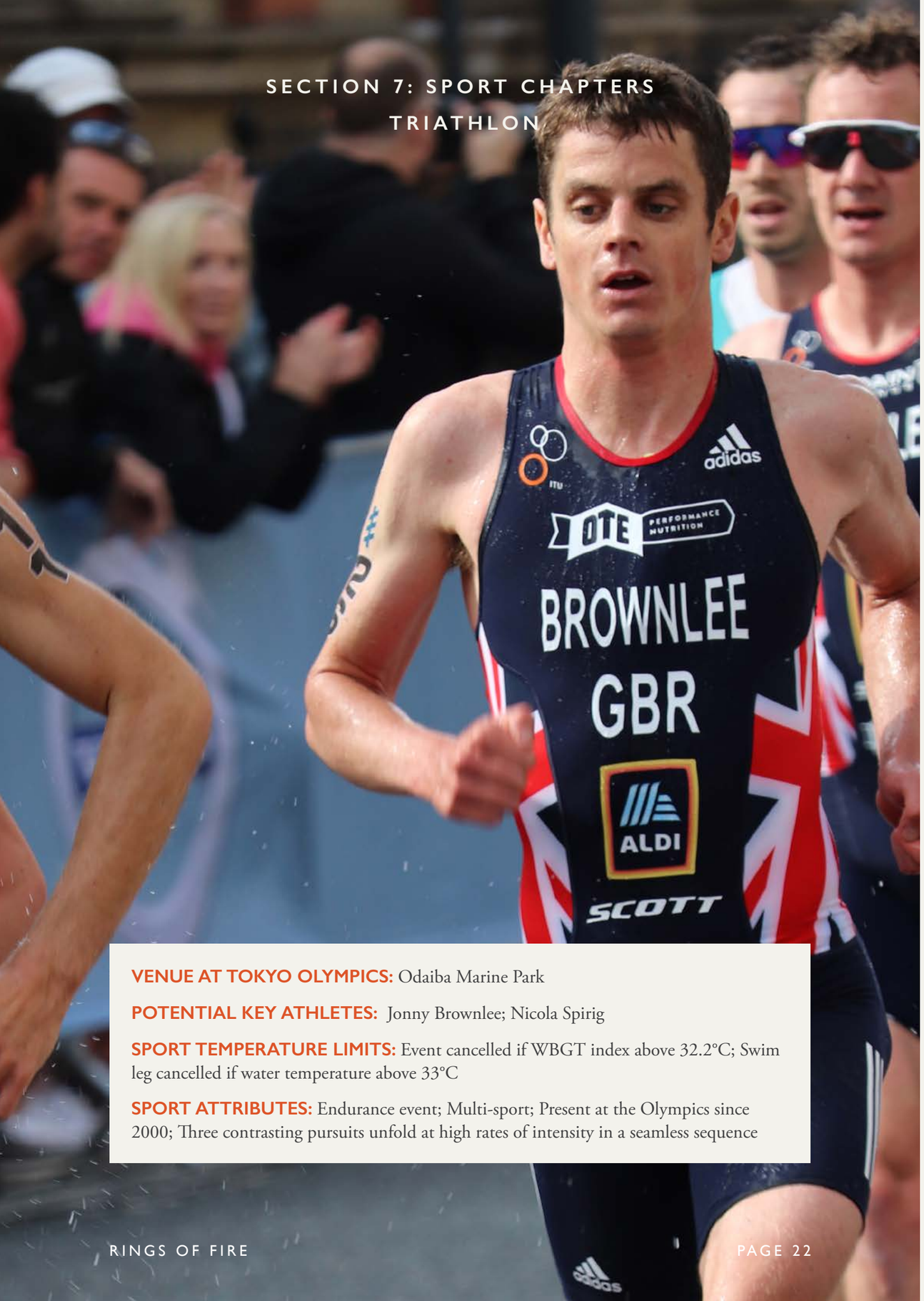
The Paralympics are due to take place between August 24th to September 5th when high temperatures will still be a consideration in Tokyo[12]. This is illustrated by the decision by organizers[13] in 2019 to move the Paralympics marathon forward to a 6:30am start time.

Paralympic athletes across the different sports will face the same issues as those taking part in the Olympics a few weeks earlier.

However, extreme heat can pose additional challenges for Paralympic athletes due to their impairment, which is often associated with symptoms and thermoregulatory challenges specific not only to that impairment but also to the individual. Athletes with a spinal cord injury are unable to thermoregulate efficiently below their lesion, with sweating and consequently evaporative heat loss impossible. Skin health is an ongoing issue for many athletes with a prosthetic limb, which is exacerbated in the heat with swelling and increased sweat. There are also a wide range of consequences of heat on athletes with neurological conditions. Each athlete needs to be assessed individually to understand the impact their condition may have on their ability to tolerate the conditions.

Preparation for performing in the heat has historically been confined to athletes competing in endurance-type events such as triathlon and marathon, to ensure that performance is not impaired. However, the potentially extreme conditions in Tokyo have necessitated support staff to consider the impact on Paralympic athletes, not only during performance, but whilst living and thriving in the environment for the duration of the time that they are in the country.

A number of academic studies have noted the relative paucity of research into the effects of competing in hot environments for Paralympic athletes [14, 16]. However, there is an increasing awareness of the risks and a resulting focus on recommendations for combating them, which include enhanced cooling techniques, developed heat policies, heat acclimation and hydration strategies [16].



SECTION 7: SPORT CHAPTERS
TRIATHLON

VENUE AT TOKYO OLYMPICS: Odaiba Marine Park

POTENTIAL KEY ATHLETES: Jonny Brownlee; Nicola Spirig

SPORT TEMPERATURE LIMITS: Event cancelled if WBGT index above 32.2°C; Swim leg cancelled if water temperature above 33°C

SPORT ATTRIBUTES: Endurance event; Multi-sport; Present at the Olympics since 2000; Three contrasting pursuits unfold at high rates of intensity in a seamless sequence

Triathlon is a race consisting of three different sports- swimming, cycling and running. The distances for a triathlon vary, but in the Olympic format involve swimming 1.5km, cycling 40km and running 10km. Although at the highest level triathlon is a European-centric sport, it commands a growing global appeal with thousands of individual races taking place around the world each year- from Hawaii to Nice to Alcatraz Island. Paratriathlon similarly consists of three disciplines, but takes place over a shorter distance for the swim (750m), bike (20km) and run (5km). There are six different classes depending on the nature and extent of the impairment. In the seated class, athletes use a hand bike for the cycle segment, and a wheelchair for the run.

Professor Julien Périard, from the University of Canberra Research Institute for Sport and Exercise, summed up the unique challenge triathletes face for this report:

"Normally, when someone goes out for a run or running race, their core temperature increases as they progress. It may be elevated slightly by warming up, but once they start running at a high speed and metabolic rate increases (i.e. heat production), core temperature rises. During a triathlon, the athletes have already swum and cycled, so they enter the run segment of the race with a body core temperature that is higher than it normally would be at the start of a run. Given that elite athletes are motivated and run at very high speeds, the amount of heat they produce leads to a further rise in core temperature. This is likely the biggest challenge they face from a heat illness perspective."

The issue of heat illness for triathletes was cast into the spotlight during the Triathlon World Series in Mexico in 2016 when Jonny Brownlee was helped over the finish line by his brother Alistair [17]. Alistair recalled the moment and its wider significance for this report:

"Racing in the heat adds extra layers of physical and mental challenges. The results of getting it wrong can be dangerous and even fatal. I saw this first hand when my brother, Jonny, (a little famously) got it wrong in Mexico and suffered from heat stroke."

Those dramatic scenes became laden with a wider symbolism- of fraternal loyalty, of sacrifice, of the sheer guts and gumption it takes to make it as an elite endurance athlete. But the pictures also vividly exemplified the impact that extreme heat can have on performance and health.

Alistair himself, a double Olympic champion, has experienced the debilitating physical and mental effects of heat stroke:

"There have been a few occasions when I have pushed too hard in hot conditions and given myself some kind of heat related illness. The first was in a race in London in 2010 when I pulled up 300m before the line. I eventually finished but can't remember anything from 300m out to waking up on an ICU bed.

You first have to be pushing very hard and ignoring feelings of physical discomfort. This makes you feel hot and very uncomfortable. Eventually your skin might start feeling cold; this is apparently because of the reduction of peripheral circulation (to the skin) to prioritise core circulation. The next stage (for me) was complete shut down and I can't remember any of it. The brain stem is prioritising brain function at this point and trying to stop movement. In my case, I still finished the race, very slowly and with no memory of it. I came back to consciousness on a hospital bed covered in ice!

Athletes' health is endangered by competing in extreme heat and humidity It's a concern for everyone."

The Brownlee brothers are not alone in suffering the frightening effects of heat strain. According to Ben Bright, head coach at the

British Triathlon Federation, the issue has increased in importance for the International Triathlon Union in the wake of a number of alarming occurrences:

"I would say that, due to the Olympics being held in Tokyo, the issue of extreme weather has been highlighted but it is something that has been building in the past few years.

There have been multiple instances. At the 2019 Test Event in Tokyo, the Women's individual run leg was shortened due to extreme [heat] conditions and the paratriathlon event had the swim cancelled due to water quality issues. Even with this [change] in the women's event there were many athletes who did not finish or who were in distress post-race due to conditions.

There is an annual event in Hualtaco in Mexico that has been changed from Olympic Distance to Sprint (2hrs to 1hr) due to multiple instances over the years of athletes suffering from heat illness in extreme conditions."

There are additional considerations and added levels of risk for Paralympic competitors in this event. While the shorter distance in some ways reduces the risk of heat illness, other aspects of the event increase the risk. One such being the hand bike, in which the athlete is just inches away from the ground. In a hot environment with a high solar load, the tarmac can reach temperatures of 50°C or more which results in a considerable increase in the radiative heat gain transferring from the road surface to the athlete. In addition, the surface area of the athlete's body interfacing with equipment in a wheel-chair or hand bike is far higher than that of an athlete on a bike. This further reduces the opportunity for heat loss through the normal channels.

The international federation have subsequently worked with Professor Périard at the University of Canberra, together with the University of Loughborough, to produce the 'Beat the Heat' [18] document to help prepare triathletes and paratriathletes for the weather conditions at the Tokyo Games.

Professor Périard gave this report an overview of his principal conclusion:

"My main takeaway from authoring the report was that heat illness is a serious issue that can lead to severe health consequences. As such, it was important to provide not only practical recommendations, but information regarding the effects of heat stress, along with how each mitigation strategy influences the development of hyperthermia."

Temperature bands are one such mitigation measure. The following parameters, outlined by Ben Bright, were developed by the ITU's medical team:

"Air temperature/conditions are based on Wet Bulb readings. These take into account ambient heat, humidity and radiant heat stress from direct sunlight:

BLACK	EXTREME RISK	ABOVE 32.2°C	EVENT CANCELLED
RED	VERY HIGH RISK	BETWEEN 30.1°C AND 32.2°C	RUN IN AN OLYMPIC DISTANCE TRIATHLON SHORTENED FROM 10KM TO 5KM. THIS HAPPENED AT THE TOKYO TEST EVENT IN 2019 IN THE WOMEN'S EVENT
ORANGE	HIGH RISK	BETWEEN 27.9°C AND 30°C	EVENT CAN BE RUN AS NORMAL BUT PLAN TO MITIGATE RISK AND MONITOR AT RISK INDIVIDUALS CLOSELY
YELLOW	MODERATE	BETWEEN 25.7°C AND 27.8°C	NORMAL
GREEN	LOW	BELOW 25.7°C	NORMAL

The swimming component in triathlon poses a particular problem when it comes to water temperature, as Bright explains:

"The difficulty with swimming in hot water is the body is unable to effectively get rid of heat. When hot, the body transfers as much of that heat from the core to the extremities as it can. This is so it can throw offtransfer as much of that excess heat as possible through radiation (like a heater chucking out heat), convection and conduction (movement of heat and transfer to another element – air) and liquid and air cooling (air movement over sweat). When in hot water, the ability to lose heat through sweating is taken away and radiation, convection and conduction is restricted."

Bright adds that water temperature limits, brought in by the International Swimming Federation and tailored for triathlon following the death of an elite competitor [19] at an event in the Middle East, are:

ABOVE 33°C	SWIM IS CANCELLED
32-32.9°C	EVENTS WITH SWIMS UP TO 300M CAN BE HELD. EVENTS WITH SWIMS LONGER THAN 300M SWIM ARE CANCELLED
31-31.9°C	MAXIMUM SWIM DISTANCE IS 750M, SO AN OLYMPIC DISTANCE TRIATHLON WOULD GO FROM A 1500M SWIM TO A 750M SWIM.
UP TO 30.9°C	SWIM DISTANCE AS PER NORMAL

According to Bright, these regulations were updated after the Tokyo test event and are unlikely to change further before the Games. Other measures taken include the changing of event start times [20] to earlier times in the day to avoid higher water and air temperatures.

However, although these measures, along with other actions such as heightened medical provisions and developed hydration strategies, are welcomed by the elite triathlon community, Bright issued this stark warning that as long as temperatures continue to rise, there is no silver bullet:

"It is not possible to eliminate risk and it will be largely down to the specific weather conditions in the days leading into and on race days. The difference of 1-2 degrees on a race day will have a major impact on whether the event is safe to run and this is not something the event organisers can control.

I think the ITU are progressive and genuinely have athlete safety as a priority but they are also fighting to find a balance between athlete safety and external/stakeholder pressures and I think they could do with more support to understand where the lines are."

TENNIS

VENUE AT TOKYO OLYMPICS: Ariake Tennis Park

POTENTIAL KEY ATHLETES: Novak Djokovic; Naomi Osaka

SPORT TEMPERATURE LIMITS: Individual tournaments have their own guidelines. For example, at Wimbledon the heat rule provides for a 10-minute break to be taken between the second and third set for best-of-three set matches, or between the third and fourth set for best-of-five set matches, when the WBGT is at or above 30.1°C [21]. At the Australian Open, play suspension is only used as a last resort, implemented when their 1-5 Heat Stress Scale reaches the highest possible category. The Scale is similar to the WBGT in that it combines humidity, air temperature, radiant heat and wind speed [22].

SPORT ATTRIBUTES: Racket sport; requires speed, agility, flexibility, strength; Aerobic and anaerobic fitness; High level of co-ordination and perceptual-cognitive skills to continuously make rapid decisions on court.

Tennis is a hugely popular global sport that featured in the early Olympics before returning fully to the program in 1988. It is played- both in the singles and doubles format- on various surfaces and its four major international competitions take place in the UK, Australia, France and the USA in the warmer seasons of those respective locations.

The sport demands short, sharp bursts of exertion that are repeated on a continuous basis throughout a match. The quick turnaround between one point ending and another beginning and the direct, fast-paced nature of the competition between opponents requires stamina over prolonged periods.

The challenge of thermal strain and sweat loss is exacerbated by long, duelling rallies and the fact that matches have no set time limit. This has resulted in some marathon matches, including an encounter between Nicolas Mahut and John Isner at the 2010 Wimbledon Championships which lasted 11 hours.

As well as the requisite stamina, competitive tennis players must also draw upon a reservoir of mental endurance and cognitive skill in order to make split-second decisions around court strategy and shot selection.

The physical and mental challenges ensure that players are especially vulnerable to the effects of playing in extreme heat and in recent years increasing attention has been drawn to the issue, with Novak Djokovic, one of the game's all-time greats, urging the tennis authorities to factor in the heat when scheduling matches at the Tokyo Games, stating in 2019:

"There will be a lot of matches, a lot of players: men, women, doubles, mixed doubles. All of that needs to be played within less than 10 days or so. It's quite a challenge for the organisation to come up with the right schedule, I guess, where you avoid the biggest heat, but how can you really do it? That's the question. With heat, it is going to be very, very tough for players and for fans, for anybody who is in the stadium." [23]

Kevin Anderson is a vastly experienced player who has reached two Grand Slam singles finals and a career-high ranking of world number five. The South African explained to this report how heat can dictate his technical and tactical approach:

"Heat is just one of the many factors we have to take into consideration to prepare for when playing matches. Especially in the middle of summer, outside, if there's humidity. It might change what type of hydration we need before, during and after, or strategy as far as trying to shorten the points and not get into long rallies.

We've had some tough days in Melbourne at the Australian Open in years past as well as in New York City at the US Open. We also often play a few tournaments in the middle of the United States in July and August, which can be very hot and humid as well."

The significance of the impact on the style and quality of the tennis being played is of course overshadowed by the heightened risks to the health of players.

Indeed, more and more players have spoken out in recent years about the toll playing in extreme heat has taken on their bodies.

In 2014, Andy Murray shared his experiences of playing at the Australian Open:

"It's definitely something that you have to look at a bit. As much as it's easy to say the conditions are safe, it only takes one bad thing to happen. And it looks terrible for the whole sport when people are collapsing, ball kids are collapsing, people in the stands are collapsing. That's not great.

"I know when I went out to hit before the match, the conditions at 2.30, 3pm were very, very tough. Whether it's safe or not, I don't know. There's been some issues in other sports with players having heart attacks." [24]

At that same tournament temperatures reached 43°C. It got so hot that players' shoes began to melt [26].

According to Professor George Havenith, Professor of environmental physiology and ergonomics at Loughborough University, players at the 2014 tournament were producing the heat equivalent of approximately 20 60 watt light bulbs [26].

The debilitating effect on the body was exemplified by Peng Shuai of China vomiting during her match against Kurumi Nara. A ball boy and Canadian player Frank Dancevic also collapsed on court. Dancevic labelled the conditions 'inhumane' and echoed Andy Murray's concerns:

"Being out there for a set and a half and passing out with heatstroke is not normal. Until somebody dies, they just keep going on with it and putting matches on in this heat." [27]

Those distressing scenes during the 2014 heat wave - which, according to scientists, was made more likely as a result of climate change [28]- caused the Australian Open to change their heat policy [29].

The International Tennis Federation (ITF) went on to underscore the importance of the issue in their 2019 pamphlet on heat, outlining the physiological impacts of playing tennis in a warm environment, with the body generating heat as the player moves around the court in explosive and dynamic spurts of energy. The evaporation of sweat - which is the body's protection against overheating- is impeded by factors such as heat and humidity. Heat radiation from the court surface and the lack of air flow caused by the typically compact structure of an elite tennis court stadium have also been cited as compounding the effects of the direct glare of the sun for players [30].

The pamphlet further highlights the perils of ignoring or underestimating the risks of playing in heat:

"Exercise and in particular playing tennis in the heat can be potentially harmful and even life threatening to the individual. Players, coaches and tennis officials including umpires should be aware of the potentially catastrophic consequences of playing in the heat." [31]

The fact that, five years after the events in Melbourne, the ITF released this pamphlet highlights how the problem has not gone away. Indeed, the clamour of those expressing their unease has grown louder as intense heat has become a perennial part of the Australian Open. [32]

In 2015, soaring temperatures again affected play, with Adrian Mannarino retiring with heat exhaustion [33].

Later that year, new data analysis in a University of Melbourne scientific study revealed how temperatures had been rising steadily over the previous 25 years, with an even sharper rise occurring within the two-week period in January when the Australian Open takes place (Melbourne's highest January temperature increased on average by 3.25°C between 1990 and 2014) .

In 2016, blistering conditions led to players having to resort to wrapping ice packs around their heads [34] during breaks of play to try to stay cool, while once again a ball boy collapsed with heat exhaustion.

An even hotter competition was to come in 2018 when court surface temperatures hit an incredible 69°C [35], sparking fear for the safety of fans and players. Some of the game's top stars recounted their brutal experiences, with Gaël Monfils remarking, "I'm telling you, I was dying on the court for 40 minutes […]. We put our body at risk", while his opponent Novak Djokovic admitted he was physically and mentally "right at the limit". [36]

And again the Australian Open hit the headlines in 2020, this time when the effect of the heat was amplified by the raging bushfires [37]. The combination of smoke and heat got so bad that Slovenian Dalila Jakupovic collapsed during a coughing fit and had to be helped off the court whilst abandoning her qualifying game.

"I never had breathing problems," Jakupovic told The Associated Press. "I just couldn't breathe anymore and I just fell on the floor." [38]

Once more the tennis community was shocked and a candid debate about how player welfare was being undermined by the conditions ensued [39], as other players in Melbourne complained of sore chests and the tournament itself was jeopardised [40]. Temperatures soared to 43°C as competition organizers had to activate the latest version [41] of their extreme heat policy, which had been updated in 2019 and implemented measures such as a 10-minute break between a sets.

It is clear that playing tennis in extreme heat can be a gruelling and dangerous experience for players, ball boys and girls and even spectators, while the usual levels of skill and technique are diluted for those watching at home. Although measures such as incorporating additional cooling breaks for players have been announced [42] and the likes of Djokovic have highlighted the need for careful consideration around scheduling, with 172 players competing in five events over a nine-day period logistically it will be impossible to move all matches to a later start.

A headache for the organizers. For the players, they know they could suffer much worse.

VENUE AT TOKYO OLYMPICS: Sea Forest Waterway

POTENTIAL KEY TEAMS: GB; Germany; New Zealand

SPORT TEMPERATURE LIMITS: Special precautionary measures required by World Rowing where thermal risk is deemed to be high or extreme [43].

SPORT ATTRIBUTES: High intensity; Team and individual events; Cardiovascular and muscular endurance.

Rowing is one of the oldest Olympic sports, having had a presence at the Games since 1900. At the Tokyo Games, there will be 14 separate events involving 526 athletes in the Olympics and an additional four Paralympic events involving around 100 athletes. The events are made up of two different styles of rowing – sweep, where a single oar is used, and sculling, which sees athletes using two oars. The sport is especially popular in countries such as the UK, the United States, New Zealand and Germany.

The standard length for an Olympic race is 2km. World record times vary from between 5-7 minutes, with environmental conditions playing a pivotal role in determining times.

The intense cardio nature of the physical exertion within a relatively narrow timeframe brings the issue of extreme heat into sharp focus for rowers, especially given their position on the water in direct sunlight.

This was particularly evident at the Tokyo Olympics test event in August 2019 when three rowers required medical attention after suffering from suspected heatstroke, with temperatures reaching 33.7°C before 10am. Other athletes were reported to be uneasy on their feet during the award ceremony, whist a spectator was also reported to have been treated for heat illness [44].

Great Britain rower Melissa Wilson has experienced first-hand how extreme heat can exacerbate the already strenuous demands placed on a rower's body.

"I raced in Plovdiv in 2015 and again in 2018. On both occasions, getting to the course and leaving the bus I would feel like I was walking out onto Mars. The heat would stick in my throat, making me feel lethargic even moving from the bus to the course, or carrying the boat to the water. Rowing races will leave you in a lot of pain from the first half-minute onwards, with lactate burning through your muscles and your lungs struggling to get enough oxygen in.

Adding the heat of the air into the mix adds an extra layer of physical challenge - your throat burns and doesn't really recover between races as it does in a more temperate climate. You've also added that extra physical discomfort into everything else that you're trying to draw your concentration from, to stay totally focused on executing the best race possible.

You want to be lining up for your World Championships or Olympic Final feeling on top of the world, with your batteries fully charged, raring to go. Instead, in those kinds of conditions you're having to focus on just keeping your breathing steady, staying calm in conditions that people don't even want to sit in, let alone race at maximum capacity."

The World Rowing Federation have recognized the dangers engendered by training and racing in heat, issuing a set of safety guidelines which state that, *"Training and racing often occur at the hottest time of the year and thus rowers are at risk for heat related injuries. Hot conditions create a health risk for rowers, officials and spectators."* [45]

The guidelines set out a hot weather risk evaluation table, with three categories of Moderate (25° – 31.9 °C ambient temperature / 24.0 – 29.3°C WBGT), High (32° – 38 °C ambient temperature / 29.4 - 32.1°C WGBT) and Extreme (38°C and above ambient temperature / 32.2°C and above WGBT).

When the High threshold is reached, the advice is that "training and racing schedules should be modified". At Extreme risk, "training should be postponed. Regatta schedules must be modified and special provisions are to be taken in relation to the particular conditions of the venue and the regatta".

The guidelines also state that, "In general, with proper planning and observation of local weather forecasts it should not be necessary to cancel a regatta. For the safety of participants, changes can be made in the regatta schedule so that events take place in the cooler parts of the day".

However, for rowers such as Melissa Wilson, the fear is that even provisions such as these are not enough on their own to create a safe competitive environment.

"The biggest thing we should be doing is act to prevent further global temperature increases through how we're tackling the climate crisis. Physiologists can help athletes and teams with strategies to mitigate extreme heat for the time being, but if we keep going as we are I think there'll come a point where competing becomes untenable.

I think we're certainly approaching a danger-zone. There's a lot of anxiety around the finish line of some of the hotter racing locations, with life boats out to attend to and transport athletes who have passed out from heat exhaustion. It's a horrible moment when you see athletes cross the line, their bodies fling back in total exhaustion, and then not rise up."

MARATHON

VENUE AT TOKYO OLYMPICS: Sapporo

POTENTIAL KEY ATHLETES: Eliud Kipchoge; Ruth Chepngetich

SPORT TEMPERATURE LIMITS: No official parameters or limits; A temperature of 10°C- allied with low humidity- cited as optimum marathon conditions [46].

SPORT ATTRIBUTES: Road-running endurance event; Body loses fluid by sweating and breathing; Fatigue and dehydration fundamental challenges.

Marathon is a long-distance race comprising 42.195km that many view as the ultimate endurance test. It requires athletes to complete around 40,000 steps, which Olympic champions have tended to do in just over 2 hours.

With athletes producing a 30-40 fold increase in heat and losing 3-6 litres of sweat [47], the thermoregulatory demands placed upon the body by completing such a long distance in a relatively short period of time ensure that marathon runners are especially vulnerable to extreme heat.

Marathon events take place globally across seasons and a variety of climates and routes. However, in recent years top athletes say extreme heat has had an increasing impact on their performance- from the 2010 Delhi Commonwealth Games [48] to the 2016 US Olympic trials in LA, which one participant described as 'apocalyptic' [49].

One of the most high-profile examples of this was at the 2019 World Championships in Doha. Despite organizers moving the event to midnight to try to combat the gruelling heat, in the women's marathon 28 out of 68 runners failed to reach the finish line [50] as the race began and ended with a temperature of 32°C and 74% humidity.

Lyndsay Tessier from Canada was one of the athletes to finish, but in doing so she had to radically adapt her running plan to factor in the heat.

Her coach Steve Boyd, a vastly experienced veteran of the Canadian long-distance running scene, outlined the impact on her performance to this report:

"Lyndsay had to adjust her goal pace by 20 seconds per km in order to be sure of completing the distance. Even then, she lost another 2 seconds per km, in spite of performing extremely well against the competition.

If pace is not adjusted performance- and physical health- can be very significantly impacted. Athletes who fail to heed these effects very often fail to finish the marathon distance, with those who persist frequently requiring medical attention."

Tessier herself commented in the immediate aftermath of the event on the draining physical and psychological effects:

"You see somebody down on the course and it's just extremely grounding and scary. That could be you in the next kilometre, the next 500m. It was just really scary and intimidating and daunting. So that was enough to hold me back. I'm just really grateful to have finished standing up." [51]

Others to speak out included Haji Adillo Roba, the Ethiopian squad's marathon coach, who remarked, "We never would have run a marathon in these conditions in our own country", while fifth-placed finisher Volha Mazuronak of Belarus said, "The humidity kills you. There is nothing to breathe. I thought I wouldn't finish. It's disrespect towards the athletes" [52].

World Athletics, the international athletics federation, defended the decision to host the championships at that time of year in Doha [53], with president Sebastian Coe stating at the time, "The athletes talking about externalities are probably not the ones who are going to be walking home with medals from here" [54]. However, the chaotic scenes and rising anger amongst athletes led to a wave of headlines around the world [55].

Olympic organisers, keen to avoid a repetition of such a scenario, subsequently moved the Tokyo event 800km north to Sapporo, where temperatures are often as much as 5-6 °C cooler during the day than in Tokyo [56].

However, as well as failing to nullify the concerns of coaches such as Boyd, the move has had significant political, logistical and financial repercussions [57].

SECTION II:
SPORT CHAPTERS EQUESTRIAN

VENUE AT TOKYO OLYMPICS: Equestrian Park

POTENTIAL KEY ATHLETES: Sophie Christiansen; Pepo Puch; Charlotte Dujardin

SPORT TEMPERATURE LIMITS: The International Federation for Equestrian Sports (FEI) state in their rulebook: "Competitions must not take place in extreme weather conditions that may compromise welfare or safety of the Horse. Provision must be made for cooling conditions and equipment for Horses after competing". Guidance also includes: "Unless cooling facilities equivalent to FEI standard are in place at an event, the FEI strongly recommends that riding activities be suspended when the WBGT index reaches or exceeds 32-33ºC" [58]. Individual federations have also issued their own guidance. For example, Equestrian Australia's Hot Weather Policy includes a table of recommendations that correspond to a temperature scale- a recommendation for when the WBGT index goes above 33ºC states: "These environmental conditions are very high risk and are probably not compatible with safe competition" [59].

SPORT ATTRIBUTES: Dressage requires athletic skill and deep bonds of trust between horse and rider; Artistic finesse and elegance are highly prized.

Equestrian events have featured at every Olympic Games since 1912, while every Paralympic Games since 1996 has featured a Para Dressage competition. The equestrian disciplines at the Olympics are Dressage, Eventing and Jumping.

The example used here to highlight the challenges of hot climates on equestrian is the discipline of Dressage.

Considered to be the "highest expression of horse training" [60], the same general rules apply to all Dressage events at the Olympics and Paralympics.

With the exception of the Freestyle test, which is performed to music and individually choreographed, tests must be performed from memory at a walk, trot and canter, following a set pattern of movements.

Para Dressage has grown in popularity and participation, with the number of events surging by 122% between 2007 and 2016[61]. Britain, Netherlands and the USA are amongst the nations where the sport is most popular.

Exposure to full sunlight in the arena while wearing the traditional uniform of jacket, collared shirt, jodphurs, long boots and riding hat for protection creates an environment whereby the athlete can get hot very quickly with limited opportunity for heat loss. In addition, body heat from the horse and the physical demands for both rider and horse create a potentially high risk scenario. This is true for all riders, but is often exacerbated for Paralympic athletes who may have impairments that further affect their thermoregulatory response.

Equestrian Australia's extensive Hot Weather Policy has looked at these risks and highlights 'The 6 Minute Threshold'. This details how when continuous physical hard work goes beyond 6-6.5 minutes in a high WBGT Index environment, a "pivotal" heat stress mark is reached for horses [62].

A key principle is contained within the policy: "Humidity and heat- a dangerous mix causing heat overload. Combinations of high heat and humidity impact severely on a horse's main cooling mechanism- sweating and evaporation. A heat stressed horse can have multiple organ failure- it may collapse and die."

Rixt van der Horst is a five-time World Champion and three-time Paralympic medallist. The Dutch rider gave her insights to this report on how extreme heat affects horses both physically and psychologically:

"[The impacts include] loss of concentration, loss of stamina, dehydration, low energy level, heavy body feeling, they may show ataxia. No interest in food, drink or the environment and a reduced response to sweating. Problems such as laminitis, colic and kidney failure may occur and the mucous membranes will turn red. A high core temperature is a danger for the body cells, but also causes fatigue. The muscle strength is lower with a high core temperature. This process happens so that no more heat is produced by the muscles. It is self-protection for the body.

The horse is more difficult to cool down than a human and therefore the horse needs help to cool down sooner than we as humans. The horse heats up faster than a human and because of its large (muscle) mass also loses its heat less easily."

As a rider, Van der Horst has also experienced how disruptive and dangerous heat can be, in particular citing an event in Germany in 2013 when temperatures reached 36ºC.

"The heat can certainly have a major impact on your performance.

"[Impacts include] nausea, severe acidification of muscles, headache, black outs, shock, dehydration, sunstroke, collapsing or overheating.

[Heat stroke when riding] feels like a kind of blackout of the body: your sight turns black, you become dizzy, nauseous and your head feels overheated. Also, you feel a little bit

shivery, but hot and you feel physically sick. Your body is not functioning as it normally would and shuts down."

Leading scientific and equine consultant Dr David Marlin produced a report for the FEI that looked specifically at how heat affected horses at the Tokyo test event in August 2019.

He wrote that, "Horses exercising at maximal intensity at WBGT Index values over ~30°C are at increased risk of early fatigue, errors, falls, injuries and heat-related illness. In thermally challenging conditions it can be easy for horses to become overheated and a horse may rapidly go from being alright to at risk of heat exhaustion or heat stroke." [63]

When monitoring WBGT values at various locations around Equestrian Park, including stables and the indoor training arena, he placed the unit at the main arena "in a corner which received full sunlight all day from sunrise and which was also shielded from wind and in an area which received heavy irrigation. As such, these conditions were some of the worst that might be expected, with WBGT values peaking temporarily as high as 37°C, but typically around 34-36°C during the hottest part of the day".

Dr Marlin's report covered different aspects of the equestrian and para equestrian program, including the cross country Olympic event. Although ascertaining that, "All horses remained in good health for the duration of the event", he noted that "this course in these conditions represented a very intense physical challenge to the group of horses that competed. A significantly longer challenge in similar environmental conditions, albeit with fitter and higher ability horses, is likely to result in much increased potential for major heat-related issues."

The report also contained some key recommendations for the FEI to action, such as exploring all possibilities to "mitigate the effects of the likely climatic conditions, including reduction in distance appropriate for the conditions and bringing the cross country start time forward to avoid the highest WBGT conditions that would normally peak between late morning and mid-afternoon. As a result, the track is currently being re-evaluated."

Other recommendations to ensure "both health and performance in a thermally challenging environment such as could be experienced" at Tokyo included:

- Allowing horses enough time to recover from travel
- Minimising risk of over-exerting horses
- Changing training and warm-up
- Use of cooling techniques
- Consideration of how pioneering technology to monitor the body temperature of horses could be deployed

Speaking to this report, Dr Marlin- who has worked with the FEI at all the major events in hot climates since the 1996 Games- praised the federation and the IOC for "being extremely pro-active since Barcelona 1992 in using evidence and applying new knowledge to manage the safety of both horses and athletes in equestrian sport" and underlined the value of a considered strategy:

"The whole approach to climate mitigation is preparation and avoidance. No-one wants to see sick horses or athletes and, since Atlanta 1996, we have an extremely good record on this. One of the innovations that will be used at Tokyo this summer in equestrian is the monitoring of horses using thermal imaging cameras. Work at the test event in 2019 showed that we could estimate body temperature accurately in working horses using thermal cameras from 5-10m away. This means we can monitor without interfering with athletes but that we can also identify early on horses and athletes at potential risk and initiate interventions."

Dr Marlin's recommendations are also echoed by Van der Horst, who listed the measures she placed most importance on:

"Air-conditioned indoor stables, early start times, permission for riding in summer outfit (for the rider), plenty of shade areas at the preparing riding area (or a conditioned indoor arena), sufficient availability of ice water for cooling the horse, cooling vests and drinks for the rider, large fans with spray water to cool down horses."

Such actions can help mitigate against the consequences of extreme heat. However, Van der Horst and those within the equestrian community recognize that vigilance is of the utmost importance when it comes to protecting the welfare of horses.

"We do everything we can to make the horses as comfortable as possible. And take care of all the precautions, such as cooling boots, ice water for immediate cooling after the competition, additional supplements etc. But I personally always put the horse's well-being above the importance of the competition."

SECTION 12:

CONTRIBUTORY FACTORS THAT CAN INCREASE HEALTH RISKS AROUND HEAT & SELECT SPORTS

SPORT	EXERTIONAL HEAT STROKE RISK	HEAT ILLNESS RISK	RISK FACTORS
ARCHERY	LOW	LOW/MEDIUM	DURATION OF EXPOSURE TO EXTREME CONDITIONS
TENNIS	MEDIUM	HIGH	DURATION OF MATCH WITH ADDED HIGH PHYSICALITY
HOCKEY	MEDIUM	HIGH	DURATION OF GAME AND LIMITED OPPORTUNITY FOR RECOVERY
GOLF	LOW	MEDIUM	PLAY OFTEN UNFOLDING DURING HOTTEST HOURS
BASEBALL	LOW	MEDIUM	DURATION OF EXPOSURE TO EXTREME CONDITIONS
CANOEING	LOW	MEDIUM	REFLECTED RADIATION FROM WATER
SAILING	LOW	MEDIUM	SHADE-FREE EXPOSURE TO EXTREME CONDITIONS, INCLUDING DURING RACE BUILD-UP, AND REFLECTED RADIATION
RUGBY 7'S	MEDIUM	MEDIUM	MULTIPLE GAMES IN A DAY
FOOTBALL	MEDIUM	MEDIUM	HIGH PHYSICALITY
TRIATHLON	HIGH	HIGH	RAISED WATER TEMPERATURES
MARATHON	HIGH	HIGH	INCREASED ROAD SURFACE TEMPERATURES

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SECTION 13:

CLIMATE SCIENCE – AIR POLLUTION

BY JOANNA DYSON,
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THE LINK BETWEEN CLIMATE AND AIR QUALITY

Air quality and climate are closely linked, with climate both affecting and being affected by air quality [64]. This makes air pollution an important factor when considering the health impacts of climate change [65]. Ground level ozone, nitrogen oxides and particulate matter are the air pollutants of highest concern to human health. At ground level, ozone is toxic to life and can contribute, with nitrogen oxides, to the formation of photochemical smog which leads to decreased visibility and health concerns including respiratory and heart diseases [66]. Particulate matter can cause damage at a cellular level, leading long term to ailments such as heart and lung disease, cancer, and asthma [67]. In the short term, these pollutants can all lead to shortness of breath, pain while breathing, throat irritation and increased risk of complicating pre-existing respiratory or heart conditions [68].

The increase in global temperature of 1.1°C since around 1750 has led to an increase in ground level ozone in urban areas and an increase in water vapour in the atmosphere. Water vapour is the most abundant greenhouse gas in the atmosphere, so an increase in water vapour concentrations leads to further atmospheric warming [69].

Increased levels of particulate matter, however, can have both a warming and cooling effect on the environment. Aerosols given off most commonly from combustion sources such as black carbon absorb infrared radiation from the sun leading to a warming effect, whereas inorganic aerosols such as sulphate aerosols found in mineral dust scatter infrared radiation back into the atmosphere leading to a cooling effect. Aerosols can also affect the formation of clouds and therefore the ability of clouds to scatter radiation and cool the atmosphere [70].

Erratic weather patterns caused by changes in climate can cause the stagnation of pollutants harmful to health in urban areas, with heat waves leading to a large increase in ground level ozone and particulate matter and the exacerbation of health concerns related to these pollutants. At present, globally, seven million people die every year due to poor air quality (WHO).

HEAT WAVES AND AIR QUALITY

Heat waves, such as the heat wave in summer 2018 in Japan, are an important driver for air pollution events. Heat waves often occur at times of high atmospheric pressure. The combination of higher heat leads to an increased formation of atmospheric pollutants with the higher atmospheric pressure leading to a reduction in the ability of air currents to dissipate the pollutants into the higher atmosphere [71]. This leads to ozone and particulate matter reaching dangerously high levels in urban areas, especially where the urban heat island effect alone can increase the temperature by up to 3°C [72].

AIR QUALITY IN JAPAN

Interestingly, a large proportion of air pollution in Japan does not originate in Japan: transboundary air pollution is a huge problem, specifically ozone pollution. Japan's ozone production plateaued in the 1990s but has still been increasing since then due mostly to industry in China [73]. In addition to sources of pollution caused by human activity, mainly vehicular and industrial emissions, yellow sand pollution events are also caused by dust plumes in Japan [74]. A 2017 study by Nagashima et al. estimated that approximately 97% of the increase in ozone since the 1990s in Japan can be attributed to sources outside of Japan [75]. Studies undertaken in Japan specifically have linked poor air quality to heart conditions, intracerebral haemorrhages, respiratory and immune conditions [76, 77, 78].

LOOK AHEAD TO THE PARIS OLYMPICS

Like Tokyo, Paris is a densely populated city that experiences high levels of pollution. Long-term exposure to poor air quality (attributable to high levels of particulate matter, NO_2 and O_3) in France has been associated with approximately 42,100 premature deaths annually [79].

In Europe, population density and poor air quality exposes the public to potential health risks with the effects of air pollution being higher than the global average. Paris has been a focus of high pollution in Europe, specifically NO_2 air pollution, with NO_2 levels in Paris being consistently over the EU legal limit. A study released by the European Transport and Environment Association showed that a four-day long weekend in Paris has the equivalent health effects as smoking two cigarettes. According to research by R. A. Muller and E. A. Muller at Berkley Earth, one cigarette smoked is equivalent to a fine particulate matter concentration of 22μg/m³ a day. The daily mean for Paris is approximately 15μg/m³, thus equating to smoking 0.7 cigarettes a day.

Though there have been improvements in both NO_2 and particulate matter concentrations, the reductions are not enough to meet the EU legal limits, especially for NO_2. A recent study suggested that Paris will need 20 years at the current decreasing trajectory to achieve the European limit value (40μg/m³ annual mean- laid down by 2010 Paris Agreement) for NO_2 [80]. As such, for the Paris 2024 Olympics, the effects of high levels of NO_2, ozone and particulate matter on the athletic performance should not be overlooked.

As well as air pollution, the population of Paris is severely exposed to heat waves. France saw record-breaking temperatures in June 2019 (45.9°C, Gallargues-le-Montueux), a heat wave that killed nearly 1,500 people and was made at least five times more likely due to climate change [81]. The urban heat island effect adds up to the probability of experiencing severe heat waves, which occurred in Paris once every 10 years in the twentieth century.

Researchers from the Centre de Recherches Météorologiques (CNRS) and Météo-France suggest that, in the short term, Paris will suffer a severe heat wave event every other year [82]. Rising temperatures due to climate change on top of the urban heat island effect translate into a high probability of extreme temperatures.

SECTION 14:
TEMPERATURES AT PAST OLYMPICS

It has been 57 years since Tokyo last hosted the Olympic Games. Back in October 1964, mean dry bulb temperatures oscillated at around 11.1°C. However, the situation is looking distinctly different for these Games. Expected temperatures in the Japanese capital city are 25°C and 26.4°C in July and August respectively. Mean temperatures higher than 25°C have only been registered at the Beijing (2008), Athens (2004) and Atlanta (1996) Olympics.

GAMES	LOCATION	MEAN DAILY T (°C)	MAX DAILY (°C)	SOURCE
RIO 2016 (AUG)	FORTE DE COPACABANA	21.8	33.2	2
LONDON 2012 (27J-12A)	HEATHROW	JUL=17.2, AUG=18.9. MEAN=18.05	JUL=21.3, AUG=23.5 MAX=23.5	1
BEIJING 2008 (AUG)		26.1	30.6	1
ATHENS 2004 (AUG)		27.6	34.2	1
SYDNEY 2000 (SEP)	AIRPORT	17.6	22.8	1
ATLANTA 1996 (19J-4A)	AIRPORT	JUL=27.7. AUG=26.4 MEAN=27.05	JUL:33, AUG:31.2 MAX=33	1
BARCELONA 1992 (25J-9AUG)	AIRPORT	JUL=21.5, AUG=23.9 MEAN=22.7	JUL=25.7, AUG=28.4 MAX=28.4	1
SEOUL 1988 (17S-2O)		SEP=21.4	26.5	1
LOS ANGELES 1984 (28J-12A)		AUG=22.8	25.8	1
MOSCOW 1980 (19J-3A)		JUL=17.2, AUG=14.7 MEAN=15.95	NA	1
MONTREAL 1976 (17J-1A)		JUL=19.6	NA	1
MUNICH 1972 (26A-11S)	AIRPORT	AUGUST=16.2, SEP=10.6 MEAN=13.4	NA	1
MEXICO 1968 (OCT)		15.7	NA	1
TOKYO 1964 (OCT)		11.1	NA	1

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SECTION 15:
KEY RECOMMENDATIONS

Extreme heat has been a factor for athletes to contend with over the years. However, if current trends continue, more sports, more events and more athletes, referees and spectators will be exposed to more extreme weather conditions around the world, impacting on health, performance and the overall sporting spectacle.

As we have seen in this report, some ruling bodies and federations are making positive strides when it comes to assessing and addressing extreme heat risks.

The IOC also has made forward-looking and progressive moves around the wider associated issues of climate change, as evidenced by their alignment with the Paris Agreement, setting a target to reduce their greenhouse gas emissions by 45% by 2030 [83].

Yet the need for measures to be put in place and/or maintained and advanced continues across different sports and events. These include:

- More developed guidelines to help inform decision-making around when sporting events should be postponed, amended or cancelled due to the risk of heat illness
- Focus on pre-event athlete preparation and acclimatization strategies
- An emphasis on rehydration strategies
- More shaded areas for athletes to rest and prepare for an event
- Implementation of cooling techniques
- Provision of spectators with economical but effective sun hats when appropriate
- Thought given to the scheduling of events to avoid the hottest times of day
- Deployment of enhanced technology to monitor heat and body temperatures
- Education around the symptoms and treatment of heat illness
- Development of a duty of care charter for athletes' health, including a mechanism whereby athletes can flag concerns around climate impacts without fear of being penalised
- Strong advice given that any athlete with a suspected infection and/or a raised deep body temperature does not compete in the heat
- Greater sharing of resources and information around heat illness between different federations and sports, cascaded down from the elite level right through to the grassroots

All these factors can help mitigate against heat illness and exertional heat stroke amongst athletes, spectators, coaches and event staff, whilst also limiting heat-induced disruption to both local and global competitions.

However, ultimately the biggest change involves the biggest challenge- to reduce the actions and causes that contribute to the increasing trend of rising temperatures and evermore unpredictable weather patterns.

That is one must-win encounter, the most important prize of all.

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