



# "MY ENGINE IS OVERHEATING!": COOLING STRATEGIES FOR FORMULA 1 DRIVERS

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## KEY POINTS

- Formula 1 drivers race for 90–120 min in some of the world's hottest environments, with temperatures inside the race suit exceeding 50°C, yet cooling remains one of the most under-researched areas in motorsport science.
- Hyperthermia impairs cognitive function, decision-making, and fine motor control, all of which are critical to safe and fast driving at speeds exceeding 300 km/h.
- Pre-race cooling of the neck, body, and hands can meaningfully attenuate thermal strain and preserve cognitive performance in the period leading into the race.
- The optimal pre-race cooling window appears to be 20–40 min before the start with combined cooling strategies (cold-water immersion followed by cooling garments) more effective than any single method alone.
- Dehydration compounds the physiological burden of heat stress and independently impairs driving performance. In-race fluid intake, including chilled or iced drinks, is a primary cooling tool available once the race has begun.
- In-race options are limited to a mandated water-perfused cooling garment and fluid ingestion. Recent evidence indicates the cooling garment may not, on its own, attenuate the core temperature rise, underlining the importance of pre-race strategies.
- Drivers and their performance coaches and team medical staff should develop individualized, evidence-based cooling protocols for every "hot-race" weekend.

## INTRODUCTION

When a Formula 1 car overheats, its engineers have milliseconds to respond, adjusting radiator ducts, managing brake bias, or instructing the driver to create a gap to the car ahead. The irony is that the human being sitting inside that car may also be overheating. Yet in Formula 1 the science of driver thermoregulation has received a fraction of the attention devoted to the machine. This is beginning to change as a growing body of research is characterizing both the physiological demands placed on the driver and the evidence-based strategies available to protect them.

A Formula 1 race lasts between 90 and 120 min, and the driver is encapsulated inside a tightly fitted carbon-fibre cockpit, wearing a multi-layered flame-retardant suit, gloves, balaclava and helmet. These garments are mandated by the Fédération Internationale de l'Automobile (FIA) for critical safety reasons, and the safety suit itself cannot be modified to incorporate cooling technologies or phase-change materials. Therefore, the suit's safety properties come at an unavoidable and significant physiological cost as they substantially reduce or prevent the body's primary avenue for heat dissipation, evaporative sweating. The sport races globally, visiting circuits in Bahrain, Singapore, Saudi Arabia, Miami, and Qatar, where ambient temperatures routinely exceed 30°C and track surface temperatures can surpass 50°C (Brearley & Finn, 2013). Under such conditions, temperatures measured inside the race suit can exceed 50°C (Brearley & Finn, 2013), creating an environment unlike almost any other in elite sport.

Unlike most athletes, Formula 1 drivers cannot slow down, remove clothing, access cold towels or step into the shade when they feel hot. Once the race begins, options for managing thermal load are extremely limited. The consequences of overheating extend beyond physical discomfort. Elevations in core temperature impair cognitive function, reaction time, decision-making and fine motor control, all skills that a Formula 1 driver relies upon to safely navigate a circuit at speeds of up to 340 km/h, often separated by centimetres from rival cars (Gaoua et al., 2011). In extreme cases, heat-related illness can result in loss of consciousness and, in the context of a race car, potentially catastrophic accidents.

This Sports Science Exchange article examines the thermal challenge faced by Formula 1 drivers, the evidence base for pre-race and in-race cooling strategies, the contribution of dehydration to thermal strain, and the very real safety implications of inadequate thermal management. The aim is to translate available scientific evidence into actionable guidance for performance coaches, team medical staff and drivers themselves.

## THE THERMAL ENVIRONMENT IN FORMULA 1

Tyler et al. (2026) documented that during the 2025 Formula 1 season, drivers faced moderate heat stress (defined by a Universal Thermal Climate Index threshold) in at least seven of the 24 Grand Prix races, including events in Bahrain, Saudi Arabia, Miami and Singapore, with track surface temperatures exceeding 45°C at several venues and

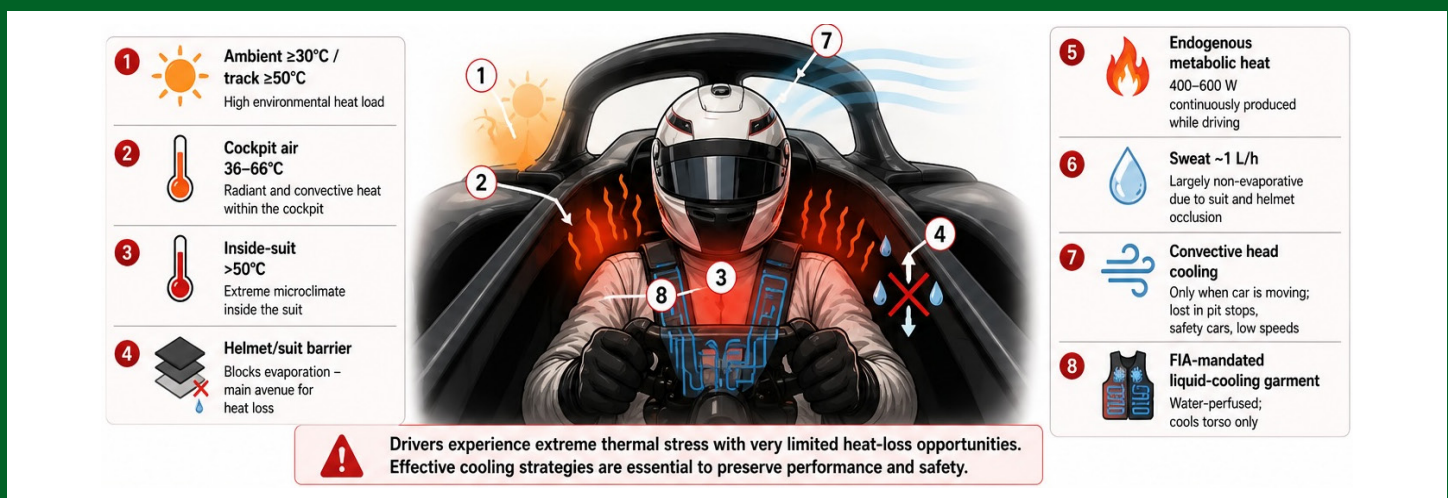
cockpit air temperatures have been recorded between 36 and 66°C (Tyler et al., 2026). While driver core temperature data from Formula 1 are unavailable due to logistical and regulatory constraints, data from closed-cockpit motorsport indicate it can rise by 1.7–2.5°C per hour during racing (Brearley & Finn, 2013; Watkins, 1995),

Formula 1 cars are open-cockpit, meaning the driver's head is exposed to airflow during racing. The open-cockpit provides some convective cooling while the car is moving. This cooling disappears during pit stops, safety car periods, or slow-speed circuits such as Monaco. The flame-retardant suit, underwear layers, gloves and helmet create a microclimate around the driver's body that severely limits evaporative cooling, the body's most efficient heat dissipation mechanism. Sweat rates of ~1 L/hour have been reported in Formula 1 drivers (Watkins, 1995). When sweat cannot evaporate from clothing-occluded skin, it provides little cooling benefit and merely contributes to fluid losses. Beyond the environmental load, drivers generate substantial endogenous heat. Elite drivers race at ~65–75% of  $VO_{2max}$ , with a 90-min open-wheel race estimated to expend ~540 kcal (Tyler et al., 2026). For a 70 kg driver with  $VO_{2peak} \approx 62 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , this corresponds to a sustained metabolic heat production in the order of 400–600 W (McKnight et al., 2019). Because the FIA-mandated suit and helmet sharply curtail evaporative dissipation, this endogenous load combines with the cockpit thermal environment to drive the rapid rise in core temperature observed in closed-cockpit motorsport (Brearley & Finn, 2013).

Formula 1, where drivers must simultaneously manage their position on track, react to rival drivers' movements, operate a complex steering wheel with more than 20 buttons and switches, interpret team radio communications, manage tire temperatures, fuel loads and battery deployment strategies, and maintain spatial awareness of cars they cannot always see, all while travelling at speeds that render even a 100 ms delay in reaction time meaningful.

Elevations in core temperature of as little as 0.8°C can impair hand-eye co-ordination and decision-making ability in drivers of regular passenger cars (Wyon et al., 1996). Gaoua et al. (2011) found that executive function, working memory, attention and processing speed are all vulnerable to heat-induced impairment, particularly once core temperature exceeds ~38.5–39°C. Crucially, these impairments can occur before the onset of voluntary fatigue or overt symptoms of heat illness. This means a driver may be cognitively compromised without fully recognizing it. Hot environmental exposure and physical encapsulation increase subjective feelings of fatigue, discomfort and mental effort (Hancock & Vasmatazidis, 2003). Importantly, elevated body temperatures increase error rates in both laboratory and occupational settings (Staal, 2004).

An individual's physiological tolerance to gravitational acceleration is significantly attenuated when hyperthermic. The seminal work of Nunneley and Stribley (1979) demonstrated that heat stress lowered G-force tolerance by 0.3 G, a finding mechanistically consistent with the marked cardiovascular impairment (reduced cardiac output,



**Figure 1:** Thermal load and heat stress in a Formula 1 driver. External thermal load (1–3) acts on a body whose primary cooling pathway is blocked by the FIA-mandated suit and helmet (4). Sustained metabolic heat production (5) and largely non-evaporative sweat (6) compound the challenge. The only driver-controlled in-race countermeasures are convective head cooling, available only when the car is at speed (7), and the mandated water-perfused liquid-cooling garment covering the torso (8)

## HEAT, THE BRAIN, AND THE DANGER OF OVERHEATING AT 300 KM/H

The brain is highly sensitive to changes in body temperature, and a growing body of literature demonstrates that even modest elevations in core temperature can measurably impair cognitive performance (Gaoua et al., 2011; Racinais & Oksa, 2010). This is of paramount concern in

stroke volume and blood pressure) that occurs when dehydration is superimposed on hyperthermia (González-Alonso et al., 1997). A driver with diminished capacity to resist the lateral and braking G-forces of Formula 1 cornering may struggle to keep their head stable. Consequently, vision and vestibular function may be compromised, both

essential to racing safely (McKnight et al., 2019). In aggregate, a driver experiencing significant thermal strain is not simply uncomfortable, they are likely to be a measurably less effective and a less safe driver than their thermoneutral counterpart. This makes evidence-based cooling strategies not merely a performance optimization, but a critical safety intervention.

## PRE-RACE COOLING: THE MOST EFFECTIVE WINDOW OF OPPORTUNITY

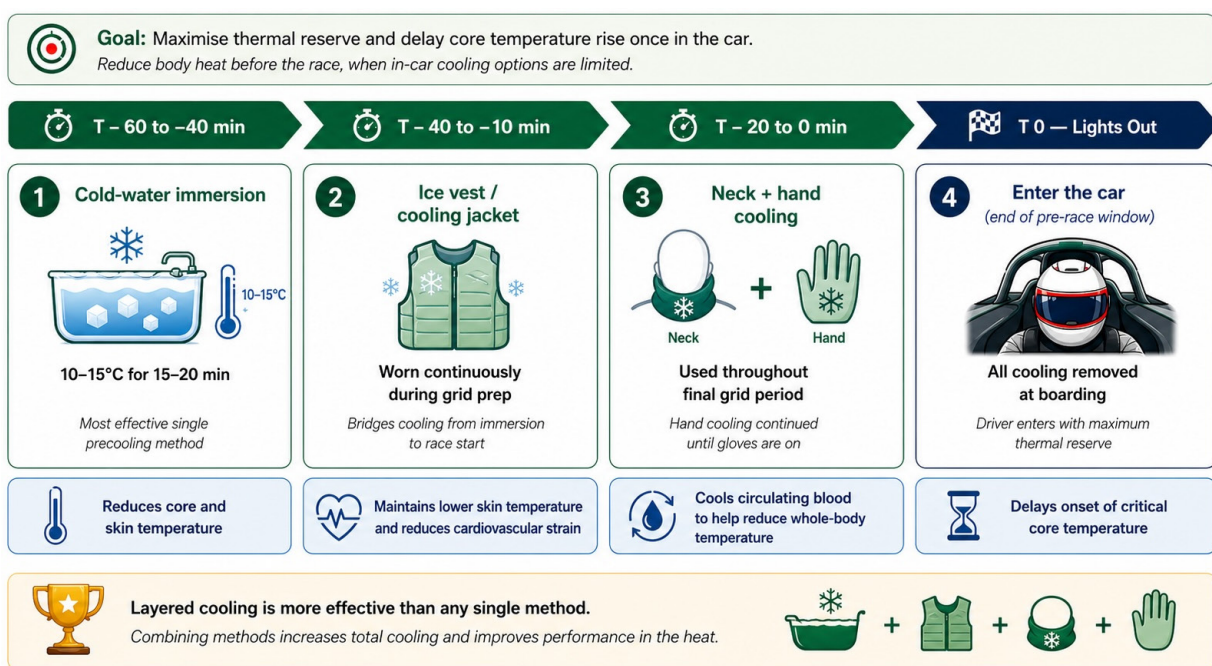
Because the opportunities for cooling during a Formula 1 race are severely limited, the pre-race period represents the primary window within which meaningful thermal protection can be established. By reducing core body temperature prior to the race start, the driver begins the event with a greater 'thermal reserve', a buffer before critical thresholds of physiological and cognitive impairment are reached (Periard et al., 2021; Tyler et al., 2015).

A comprehensive review of precooling by Tyler et al. (2015) demonstrated that combined strategies, typically involving cold-water immersion followed by cooling garments, are more effective than any single modality alone. Specifically, cold-water immersion reduces core temperature via conductive heat transfer, while cooling garments attenuate the subsequent rise in skin temperature and reduce perceived thermal strain. All three Formula 1 performance coaches interviewed by Tyler et al. (2026) pre-cooled their drivers prior to hot races. Cold-water immersion was identified as the most effective method, typically performed approximately one hour before the race, described as "the latest that we can do it based on the schedule"

(coach 2, cited in Tyler et al., 2026).

**Neck Cooling.** Neck cooling is of particular interest for Formula 1 drivers. The neck is rich in thermoreceptors and close to the carotid arteries. Consequently, local cooling of the neck has a disproportionately larger effect on perceived thermal comfort relative to the core temperature reduction achieved (Nunneley et al., 1971; Tyler et al., 2015). Given the high mass of the helmet and head-neck system (7.4 kg; Tyler et al., 2026) combined with the G-force demands placed on neck musculature during racing, any intervention that reduces neuromuscular fatigue and thermal discomfort in this region has potential dual benefit. Practitioners should note, however, that the primary mechanism appears to be perceptual as a randomized crossover trial found that an ice-filled neck collar worn throughout exercise in 35°C heat produced no significant reduction in core temperature, heart rate or sweat loss, despite significantly perceived cooler thermal sensations (Ishizuka et al., 2025).

**Body Cooling via Ice Vest or Cooling Jacket.** Ice vests and cooling jackets are the workhorses of pre-race thermal management. Studies across cycling, running, and team sports consistently demonstrate that ice vest precooling reduces core temperature, attenuates the rise in heart rate and perceived exertion during subsequent exercise in the heat, and can extend time to exhaustion (Chan et al., 2017; Quod et al., 2008; Tyler et al., 2015). The key mechanisms are an enlarged core temperature margin before critical physiological thresholds are reached and a blunted rate of cardiovascular drift (Chan et al., 2017). The recommended precooling duration is 20–40 min, with longer durations providing greater benefit but diminishing returns by the time



**Figure 2:** Recommended pre-race cooling protocol timeline. Layered application of cold-water immersion, ice vest/cooling jacket, and final-grid neck and hand cooling, completed at car entry. Each modality contributes a distinct effect on core or skin temperature, cardiovascular strain, or whole-body cooling. The cumulative benefit exceeds that of any single method (Periard et al., 2021; Tyler et al., 2015, 2026).

racing begins (Periard et al., 2021; Tyler et al., 2015).

**Hand Cooling.** Hand cooling is a less intuitive but valuable tool. The palmar surface contains a high density of arteriovenous anastomoses that allow efficient heat exchange, and cooling the hands via cold-water gloves or immersion devices can deliver meaningful systemic cooling and improvements in endurance performance (Bongers et al., 2015; Grahn et al., 2005). Uniquely, hand cooling can be sustained until the moment the driver puts on their gloves, maximizing the duration of thermal benefit.

**Recommended Protocol.** Pre-race cooling should be completed as close to the race start as logistically feasible (Tyler et al., 2015). Current evidence and practice support a layered approach:

1. Cold-water immersion (10–15°C, 15–20 min) approximately 45–60 min before the race.
2. Immediate transition to ice vest and neck cooling wrap, worn until car entry.
3. Hand cooling in the final 10–20 min before boarding.

This combined and successive approach addresses core temperature reduction, sustained skin temperature management and cooling until the last possible moment.

### IN-RACE COOLING: WORKING WITH WHAT YOU HAVE

Once the race begins, options for managing thermal strain are extremely limited by safety regulations. FIA sporting rules prohibit the addition of fans or any active cooling devices to the car, and no external cooling intervention is permitted once the race is underway. Two tools remain: the pre-fitted water-circulating liquid-cooling garment worn under the suit, and fluid ingestion. The cooling system, often referred to colloquially as a “Cool Shirt,” is a water-perfused undergarment covering the torso (chest, back and upper arms). The legs are not perfused, although designs continue to evolve. From the 2025 season the water-circulating cooling garment is mandated when the race is declared a “heat hazard” (forecast ambient temperature  $\geq 31^\circ\text{C}$ ). From 2026, the liquid-cooling garment must be fitted to and worn by every driver at every event, irrespective of forecast temperature, although activation remains at the driver’s discretion (Tyler et al., 2026).

**Fluid Intake: Cooling From the Inside.** Drinking cold or iced fluids during exercise in the heat provides a meaningful, albeit modest, reduction in core temperature. Ingested fluid cooler than body temperature must be warmed, drawing thermal energy from the core (Siegel et al., 2010). Bird et al. (2025) demonstrated this directly with eight racing drivers completing simulated 120 min races at  $40^\circ\text{C}$  and 50% humidity in full FIA attire. Cold water ( $5^\circ\text{C}$ ) produced a significantly reduced rise in core temperature as compared to ambient temperature fluid (1.17 vs.  $1.69^\circ\text{C}$ ). All eight drivers completed the cold-water trial versus only two in the ambient condition. Furthermore, cold fluid was consumed in substantially greater volumes, and warm fluid was rated as unpalatable. Ice slurry, which absorbs additional heat as it melts

in the gut, reduced core temperature by  $\sim 0.3\text{--}0.5^\circ\text{C}$  relative to cool water and extended time to exhaustion (Siegel et al., 2010; Tyler et al., 2013). The conventional manual drinking system tends to produce irregular bolus intake. Simulator research with 20 elite professional racing drivers found this resulted in greater hypohydration and lap times 4.1% slower relative to a prompted, hands-free system, despite equivalent fluid volumes (Ferguson et al., 2023). Coaches and sports dietitians are encouraged to work with drivers to identify palatable fluid formulations, optimize drink bottle temperature and practice in-race drinking during simulator sessions.

The mandated “Cool Shirt” raises important questions. The first peer-reviewed controlled comparison of driver cooling technologies, funded by the Mercedes-AMG Petronas Formula 1 Team, produced a counterintuitive finding. The Cool Shirt not only failed to reduce core temperature relative to a no-cooling control, but it was also associated with a higher core temperature ( $38.58$  vs.  $38.32^\circ\text{C}$ ) following 60 min of exercise at  $32^\circ\text{C}$  and 80% humidity in full FIA-specification attire (Davis et al., 2026). A suit-blower device produced the lowest core temperature ( $37.51^\circ\text{C}$ ), though it is not currently sanctioned for Formula 1 use. The Cool Shirt did attenuate skin temperature, but its apparent exacerbation of core heat load relative to no cooling raises important questions about its adequacy as the sole mandated intervention. The mechanism behind this paradoxical finding is likely a thermoregulatory negative-feedback effect. Cooling of cutaneous thermoreceptors signals the preoptic area of the hypothalamus to reduce heat-loss responses (cutaneous vasodilation and sweating), thereby trapping endogenous metabolic heat in the core (Ishizuka et al., 2025). Davis et al. (2026) further noted that participants reported the garment “warming up” after  $\sim 30$  min, suggesting cooling capacity declines as the chiller’s reservoir is overwhelmed by the heat load. The combination of attenuated endogenous cooling and waning device cooling plausibly explains the higher final core temperature observed in the Cool Shirt condition.

Three further findings from Davis et al. (2026) warrant attention for Formula 1 teams. First, the Cool Shirt’s effectiveness waned after  $\sim 30$  min, a meaningful limitation for 90–120 min races. Second, despite producing the highest core temperature and physiological strain values, more participants completed the Cool Shirt condition than no-cooling, indicating that cooling sensation can mask physiological deterioration and in a racing car, this dissociation carries a real safety risk. Third, system failure has been observed in  $\sim 15\%$  of motorsport events over 15 years of field research although this applies primarily to the Rini system used in the North American series. Formula 1 teams use bespoke garments with potentially different reliability, but rigorous pre-event system checks are essential. Teams should treat the mandated Cool Shirt as a regulatory minimum and invest in optimizing coolant temperature and flow rate while layering with pre-race strategies.

### DEHYDRATION: A COMPOUNDING THREAT

Dehydration and hyperthermia are not independent stressors. Fluid losses reduce circulating plasma volume, compromising cardiovascular function and impairing the body’s ability to direct blood to both

contracting muscles and the skin for heat dissipation (Sawka et al., 2015; Kenefick et al., 2010). Body mass losses of 2% or more impair endurance performance, and even mild dehydration (~1%) can increase driving errors in non-elite drivers (Watson et al., 2015). Dehydration also impairs neuromuscular performance, aerobic capacity and tolerance to gravitational acceleration (Sawka et al., 2015), and the classic finding that dehydration exacerbated heat-induced reductions in G-tolerance (Nunneley & Stribley, 1979) is of direct relevance. A driver entering the race dehydrated faces impaired thermoregulation and reduced G-force resilience simultaneously. Where gastrointestinal tolerance permits, the in-race fluid should contain carbohydrate (~30–60 g/h) and sodium (~0.5–0.7 g/L) to support glycogen sparing and fluid retention, given the ~65–75%  $VO_{2max}$  metabolic load reported for racing (Tyler et al., 2026). The performance coaches interviewed by Tyler et al. (2026) all emphasized the importance of carbohydrate intake, despite the absence of motorsport-specific guidelines.

Sweat rates of ~1 L/hour have been reported in Formula 1 drivers (Watkins, 1995), meaning over a 90–120 min race a driver could lose 1.5–2.0 L of fluid, approaching the threshold for performance impairment. Drivers should arrive at the circuit well-hydrated, monitoring urine colour as a practical indicator, and consuming 5–7 mL/kg body mass at least 4 h before race start and conduct sweat rate testing at representative circuit environments to set meaningful in-race fluid targets.

### **SAFETY: BEYOND PERFORMANCE, A LIFE OR DEATH ISSUE**

In Formula 1, where a moment of cognitive lapse or physical hesitation can result in a collision at speeds exceeding 300 km/h, thermal mismanagement is not merely a performance concern, it is potentially life-threatening. Heat-related illness exists on a spectrum from heat cramps through heat exhaustion to exertional heat stroke, defined as a core temperature exceeding 40°C with central nervous system dysfunction (Casa et al., 2015). In a racing car, the standard medical response of removing the driver from the heat source and initiating rapid cooling requires them to first safely stop the car, creating a critical window of continued heat exposure. The 2023 Qatar Grand Prix, in which multiple drivers required medical attention and at least one retired with heat-related illness, prompted the FIA to launch a formal review of extreme-heat racing conditions and mandate improved cooling provisions from 2025–2026 (Tyler et al., 2026). Symptoms reported across the grid included severe dehydration, vomiting in the helmet, blurred vision, and near loss of consciousness while driving: one of the clearest contemporary examples of heat stress overwhelming elite, highly conditioned athletes in a controlled environment. The regulatory response, while welcome, does not replace the need for team-level, individualized thermal management.

Team medical staff and performance coaches should maintain situational awareness of each driver's hydration status, environmental conditions, and personal risk factors for heat illness, including recent illness, sleep disruption, and travel demands, heading into

every hot race weekend.

Despite these stressors, severe heat-related incidents in Formula 1 remain rare. Three factors plausibly account for this. First, drivers are highly aerobically conditioned ( $VO_{2peak}$  ~62 ml·kg<sup>-1</sup>·min<sup>-1</sup> in elite drivers; McKnight et al., 2019), conferring greater heat tolerance and a wider thermoregulatory reserve than the general population. Second, all elite drivers now undertake structured heat acclimation (typically 60-min sessions, 5–10 days before hot races), pre-race cooling, and well-rehearsed hydration strategies (Tyler et al., 2026). Third, the open-cockpit design provides convective head cooling whenever the car is in motion. The 2023 Qatar Grand Prix illustrates what happens when these protective layers are insufficient. The combination of exceptionally high humidity, a tightly packed schedule, and an unusually high proportion of safety-car-free racing combined to push several drivers beyond their thermal reserve, prompting the regulatory response that followed. Beyond protecting drivers race by race, advances in cooling technology and protocols have implications for the sport itself. More effective thermal management widens the FIA's options for race timing and venue selection, reducing the need to schedule around the hottest months and hours of the day.

### **SUMMARY AND PRACTICAL APPLICATIONS**

Formula 1 drivers face a thermal challenge that is arguably unique in elite sport: extreme ambient heat, a sealed and insulating uniform, a race duration of 90–120 min, and virtually no opportunity for in-race cooling other than fluid ingestion. The consequences of inadequate thermal management, impaired cognition, reduced G-force tolerance and risk of heat illness, have direct safety implications at the highest level of motorsport racing.

The available evidence supports the following practical recommendations:

#### **Pre-race:**

- Perform cold-water immersion (10–15°C, 15–20 min) approximately 45–60 min before the race.
- Apply an ice vest or phase-change cooling garment immediately following cold-water immersion and wear until boarding the car.
- Use a neck cooling wrap or ice collar throughout the pre-race grid period.
- Apply hand cooling (chilled gloves or hand-immersion device) in the final 10–20 min before car entry.
- Arrive at the circuit well-hydrated, aiming for pale-yellow urine and consume 5–7 mL/kg body mass at least 4 h before race start.

#### **In-race:**

- Fill the drink bottle with chilled or iced fluid. Consider an ice slurry to maximize cooling enthalpy.
- Ensure the mandated “Cool Shirt” is operational and

rigorously system-checked before every hot-weather race. Although it lowers skin temperature, current evidence indicates it may not reduce, and could exacerbate, core temperature relative to no cooling, with benefits waning after ~30 min (Davis et al., 2026). Treat it as a regulatory minimum and layer with pre-race cooling strategies.

- Practice in-race drinking during simulator sessions and test days.

#### Post-race:

- Initiate active cooling immediately - remove helmet, suit and gloves and move to a cooled environment.
- Rehydrate promptly with fluid volumes matched to estimated sweat losses.

The science of cooling in Formula 1 is in its infancy. Practitioners must draw on the wider heat stress and precooling literature, and the hard-won experience of elite performance coaches, to protect the health and performance of these remarkable athletes. In Formula 1, the driver is not just the most expensive component in the car, they are the only one that cannot be replaced during a race.

The views expressed are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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