IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 22, Issue 3 Ser.14 (March. 2023), PP 31-38
www.iosrjournals.org

The Health Effects of Motorsports on Racing Car Drivers: A Review

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Abstract
Motor racing demands a high level of mental and physical fitness, just like any other sport. From a physiological point of view, endurance drivers are just as complicated as the cars they drive(Owen, King and Lamb, 2015).
Existing research demonstrates that pit crews and driver athletes face a variety of physiological difficulties, such as cardiovascular, physical, and environmental stressors. These difficulties have an impact on race performance and may put racers in danger. (Reid, 2019)
The goal of this study is to conduct a literature review of the numerous physiological effects on race car drivers, as well as new technology advancements and other interventions that can aid in improving driver safety.
The existingbody of research demonstrates that driver athletes face a variety of physiological difficulties, such as physical and noise fatigue, thermal stress, cardiovascular stress, high levels of g-force, exposure to carbon monoxide and injuries. It also reviews literature that presents safety measures and technological interventions such as systems for logging sensory inputs of drivers, accurate noise indicators, computer aided training programs and automatic fatigue detectionto overcome these effects of motorsports on drivers.
This paper adds to the literature on racing drivers' physiological consequences and is beneficial for motorsports students, researchers, and medical professionals. It can help racing car drivers, motorsports event organisers, team owners, and motorsports medical staff comprehend drivers' physical issues and focus on safety and well-being improvements.
Keywords: *motorsports, physiological effects, racing drivers, stressors, technological innovations*

Date of Submission: 10-03-2023 Date of Acceptance: 22-03-2023

I. Introduction

Motor racing is a professional and amateur automotive sport conducted on roads, tracks, and closed circuits throughout the world.Local, national, and international supervisory authorities, most notably the Fédération Internationale de l'Automobile (FIA), classify racing automobiles into numerous categories and oversee competitions (Digby, 2021).

Over the decades, with continuous improvements in racing cars, there have been corresponding increases in the challenges faced by racing drivers. Motor racing is a sport requiring the highest level of physical and mental fitness similar to that of any other athlete(Owen, King and Lamb, 2015).

There are a host of factors that exert physical, mental and emotional stresses on the drivers(Potkanowicz, 2019). The effects of these stresses range from psychological, cardiological, emotional and heat stress, fatigue, severe injuries, G-force effects, to name a few.

Before the twentieth century, racecardriving was not viewed as an athletic activity by the general public, media, or researchers (Dawson, 1979). However, after a few decades of scientific investigation, racing drivers are now considered athletes (Barthel et al., 2020).Athletes that compete in auto racing face a distinct set of physiological difficulties. There hasn't been much research or recognition of the physiological needs of vehicle racing.

Understanding the unique health risks linked with motorsports and developing measures to prevent these risks requires research. Several studies explore the impacts of vibration, noise, and g-forces on the bodies and minds of drivers, as well as the long-term effects of exposure to these factors. Overall, investigating the health effects of motorsports on drivers can improve safety and safeguard the health of those who participate in these sports (Reid and Lightfoot, 2019)

Inspite of a surge in peer-reviewed studies on racing drivers that have observed the cardiovascular, environmental, cognitive, and physical stress aspects, (Reid and Lightfoot, 2019), there is limited collation of all the effects observed in the bodies of racing drivers and methods to overcome these effects in order to improve the safety and well-being of drivers.

As a result, the purpose of this paper is to review the existing literature for the various physiological effects on racing car drivers and some of the recent technological innovations as well as other interventions that can contribute to greater driver safety.

The study specifically addresses the following research questions:

RQ1: What effects does participation in motorsports have on the physiology of the driver?

RQ2: How can these effects be mitigated?

The following is how the paper is structured. The first section provides an in-depth review of the history and evolution of motorsports globally, to provide an understanding of the context. Following that, the various physiological effects of motorsport participation on the drivers are discussed, as well as technological innovations and other interventions that can help overcome these effects. Finally, the conclusion section discusses the study's practical implications, limitations, and future research opportunities.

Motorsports and Driver Safety

According to Angus, Aylett, Henry, and Jenkins (2007, pp.1-2) in the motorsport industry, the word "motor" signifies: the “provision (construction and preparation) of cars and bikes”, while ‘sport’ refers to the “infrastructure including clubs, circuits, promotion, insurance… that is needed to participate in or view the sport”.

Motor sports are profitable activities involving the usage of motorized vehicles for racing or recreation. Motorsports variations include motor rallying, automobile racing, motorcycle racing, air racing, boat racing, kart racing, hovercraft racing, lawnmower racing, truck racing and snowmobile racing (Britannica, n.d.).

Automobile racing, also called motor racing is a professional and amateur automotive sport conducted on roads, tracks, and closed circuits throughout the world.Local, national, and international governing organizations, most notably the Fédération Internationale de l'Automobile (FIA), divide racing automobiles into various categories and oversee competitions(Digby, 2021).

Formula 1 Grand Prix (an international series of top ranked single-seat car road racing events), the Daytona 500 (an annual 500-mile motor race held at Daytona International Speedway), the Motor sport's Triple Crown, the 24 Hours of Le Mans (the world's oldest motor car race, held annually in France), the Indianapolis 500 (an annual motorcar race held at the Indianapolis Motor Speedway on Memorial Day), and the 24 Hours of Le Mans (the world's oldest motor car race, held annually (Mishra, 2021).

History

The history of motorsport spans nearly two centuries. The first known vehicle competition occurred in 1867. In terms of automobiles, drivers, and events, motor racing has undergone remarkable evolution in the past 150 years (Digby, 2021).

1894 was the very first official motor race, the Paris-Rouen race. At this early point in motorsport chronology, the only accessible combustion engine was a 3 horsepower Daimler engine. The remainder of the vehicles were powered by steam, however it was quickly discovered that steam engines were "fast" but unstable, as the champion of the Paris-Rouen race was a steam-powered De-Dion with Daimler engines powering the rest of the finishers (Digby, 2021).

Cars had evolved by the 19th century, with steering wheels becoming ubiquitous and tires made of metal and rubber instead of wood. In 1906, permanent racetracks began to be constructed, with the Aspendale Racecourse in Australia becoming the first track constructed expressly for racing, and the Brooklands circuit in England as the first paved circuit designed for motor racing. In 1908, the AIACR (the forerunner of the FIA) established the first set of rules for MNotor racing in order to battle speeds and improve the dependability of the automobiles. A minimum weight was established depending on the diameter of each cylinder to maintain structural integrity (Digby, 2021).

Due to the World War, the advancement of engine technology, and the finding of aluminum, by 1920 there was an abundance of technological innovation. This resulted in smaller, lighter engines with a higher power-to-weight ratio. The engine power of automobiles in 1900 ranged from 3 to 4 horsepower to 150 horsepower in 1900. Mercedes' debut in Grand Prix motor racing in 1922 resulted in the most significant breakthrough of supercharging, which is a method of putting more air into the engine to produce more power. Until the supercharger, Mercedes had just 54 horsepower, but with it, they had 82 horsepower. Alfred Neubauer, a former driver and famed Mercedes team manager, developed the system of communication with racing drivers. He proposed a well-structured strategy using boards and flags to allow the team to interact with the driver during races, which is still utilized in current motorsport (Digby, 2021).

Several other innovations such as the rear engine in 1939, the introduction of aluminum in body panels in 1962, the use of wings to gain time by using downforce, the notion of using the engine as a stress-bearing member of the car to decrease the load from the tires and suspension, moving the radiators to either side of the driver for better weight distribution and a more pleasurable drive, the turbocharged engine, the use of carbon fiber for body panels, and the introduction of the hybrid engine have also contributed to the development of (Digby, 2021).

However, with the improvements in the cars itself, there were corresponding increases in the challenges faced by racing drivers. Motor racing has grown into a sport worth millions of dollars that requires the same level of physical and mental fitness as any other sport. From a physiological point of view, endurance drivers are just as complicated as the cars they drive (Owen, King and Lamb, 2015).

Health and Physical Effects

Scientific literature in the area of driver science provides evidence about the physical demands of motorsports (Reid and Lightfoot, 2019; Potkanowiczand Mendel, 2013)

and establish that the race car driver is an athlete. There is also an increasing body of literature that specifically discusses the driver-athlete and driver science (Potkanowicz, 2015, Ferguson and Myers, 2018; Ferguson, Davis and Lightfoot, 2015; Jacobs et al., 2002; .Jareñoet al., 1987; Yanagida et al., 2016). Researchers are still learning more about the stresses that the driver-athlete faces when competing (Watkins, 2006;Matsumura et al., 2011;

Brearley and Finn, 2007;Ebben and Suchomel, 2012;Filho et al., 2015; Barthel et al., 2020).

Existing research indicates that the effect of different types of stress and strain on racing car drivers is yet to be fully understood(Edward and Potkanowicz, 2013). There are a host of factors that exert physical, mental and emotional stresses on the drivers. Some of the effects of these stresses are as under:

Fatigue

Fatigue is a very complex phenomenon and the resulting micro-sleeps are merely a subset of the potential causes of accidents, which can be traced to a lack of fitness or performance capability on the part of the driver. General physical and cognitive aspects such as attention and fatigue affect other cognitive processes (von Jan, Karnahl, Seifert, Hilgenstock, and Zobel, 2005). When drivers are fatigued, they are unable to prevent a collision. This is especially true in situations where braking or steering actions are required. Fatigue hampers perception and the ability to decide how to react, as well as the execution of the action(Owen, King and Lamb, 2015).

Durand et al (2014) found that in motor racing, weariness produced by long hours behind the wheel is believed to degrade final performance by reducing anticipatory movements that alter the effort exerted to control vehicle trajectory.

Azizan and Fard (2014) proposed that low-frequency vibration may cause drowsiness and a decline in alertness. Ten test volunteers were fastened in a seat attached to a vibration shaker table with a frequency range of 1 to 15 Hz, and electroencephalogram (EEG) headbands were placed on the participants. Within each of the brain activity bands, beta and theta brain activity was recorded in the frequency domain using Fast Fourier transformation (FFT) and power spectral density (PSD). According to the results of the experiment, beta brainwave activity, which represents the amount of awareness, dropped in both random and sinusoidal excitation. This study provides strong evidence that vibration contributes to drowsiness and mental weariness (Owen, King and Lamb, 2015).

Noise Fatigue

For individuals who compete in racing, noise pollution is a major worry. The noise levels that can be anticipated from a standard F3 car under stationary and drive-by conditions are supported by research.

According to research in Australia by Tranter and Lowes (2005), the noise levels produced by Formula 1 (F1) vehicles are comparable to those of a jet taking off. The National Association of Stock Car Racing (NASCR) has reported noise levels that are much greater than the 85 dB tolerable occupational daily dose (Kardous and Morata, 2010) based on the data that is currently available. An F1 race can have noise levels as high as 140 dB, which can result in irreversible hearing loss (Dolder, Suits and Wilson, 2013). However, there is currently a dearth of research on the noise connected with auto racing.

Stress

Both the drivers and the mechanics in the pits experience distinct environmental stressors as a result of auto racing which have a direct effect on physiological reactions, depending upon the car types and competition rules. The physiological stress that the motorsport athlete experiences is also influenced by other aspects of the car's design. For instance, compared to Formula 1, which permits power steering, some series (like IndyCar) do not, increasing the effort needed to manoeuvre the car. Additionally, new racing competitions for electric cars are starting to appear (such as Formula E), which protect athletes from heat and noise and ease concerns about flammable fuel and carbon monoxide (Reid, 2019).

Thermal Stress

Dehydration is a constant issue faced by drivers due to the thermal strain of competing while wearing multiple-layer fire suits and completely closed helmets in temperatures between 50°C and 60°C. According to published data, both drivers and pit crew personnel experience a variety of challenges(Reid, 2019).

Drivers face a high metabolic load necessary to perform sport-specific tasks in increased core body temperature (Ferguson et al., 2019; Carlson, Ferguson and Kenefick, 2014). During competition, race car drivers don fire-resistant suits with a clavule (a measure of the thermal qualities of clothing) of 1.56 (Carlson, Ferguson and Kenefick, 2014), which is comparable to a low-temperature skiing suit, along with shoes, stockings, gloves, balaclavas, and helmets. As a result of the insulated race suit, it is difficult for racing car drivers to reduce body temperature by perspiring, which is concerning given that the temperature in a race car's cockpit can frequently range from 32°C to 58°C depending on the location of the drive train, the track's ambient temperature,and the flow of air through the cockpit(Carlson, Ferguson and Kenefick, 2014). Prevailing literature on firefighters, military personnel, astronauts, and hazardous substance workers reveals that insulated clothing provides a microclimate between the wearer and the surrounding environment. The characteristics of such clothes do not provide an accurate evaluation of the ambient environment to determine the core body temperature (Cramer and Jay, 2016).

Potkanowicz (2018) reported that drivers competing in the Petit Le Mans had core body temperatures between 38.78 and 38.42 degrees Celsius. Similarly, Barthel et al. (2020) showed that the core body temperatures of professional and amateur sports car drivers during competition were 38.4°C and 38.2°C, respectively. Data from Ferguson et al. (2019), refutes the conventional wisdom that as a result of their menstrual cycle, female drivers report greater physiological fatigue while driving than their male counterparts. The authors argue that factors more than just the menstrual cycle affect thermal stress and performance, such as the type of vehicle being driven (open vs. closed cabin) and the length of experience.Drivers of race cars must control their cars at great speeds in a condition when they are subjected to physical strains like heat, vibration, and g forces (Fergusson, 2018). The heat created by the race car's drive train, ambient temperature of the racetrack and the amount of metabolic heat produced by the driverall contribute to thermal strain, which may be the most severe stressor experienced by race car drivers (Carlson, Lawrence and Kenefick, 2018).

The drivers' three-layer fire-resistant outfit, which inhibits evaporative heat loss, is especially significant in producing thermal strain. Racing drivers frequently shed 3.5 kg of perspiration during a 4-hour race, exposing them to the risk of heat illness. This is the clinical relevance of thermal strain (Brearley and Finn, 2007).

Cardiovascular Stress

The physical stress experienced by motorsport athletes is increased by the specific environmental problems involved with racing (such as noise, temperature, and carbon monoxide exposure) in addition to the physical stressof operating the vehicle. Physical stress is a reflection of the muscular effort needed for vehicle control and posture control under high gravitational (g) loads and these conditions make athletes more susceptible to exhaustion. Cardiovascular stress is one of the impacts of this physical stress since it causes persistent increases in cardiac output, heart rate, and consumption of oxygen in both drivers and pit athletes (Reid, 2019)

According to Brearley and Finn (2007), physiological strain index (PSI) values in long-form V8 Supercar competition can reach levels of 8, or "high," on a scale from 0 to 10.

Gravitational Force (G-force)

Changes in the speed or direction of a racing car can expose the driver to g-forces along any axis.Previous research has looked at effect of g-force on racing drivers.

In the horizontal plane, the g-force along the lateral axis is related to the radius of the turn and the speed of the car, while the g-force across the longitudinal axis is closely linked to the rate of change in speed. When the track layout changes, like when a car goes over a hill or around a banked curve, g force is created across the vertical axis.The scale of g forces exerted on the driver is considerable. During cornering and braking, lateral forces in automobiles that generate aerodynamic downforce can surpass 5g (Altmann, Benbow and Bouchard, 2011). On the banked bends of speedways, racing cars are able to produce comparable g forces along the vertical axis. At Daytona, Dover, and Bristol, NASCAR drivers experience 2.3, 3.5, and 4.0 vertical g, respectively.

Resistance to g-force is one of the most physically demanding tasks for a driver, with the head and neck being more susceptible. Taking into account that a driver's head wearing a race helmet weighs about 6.4 kg, an effective lateral force of 249 N is created under heavy (4g) braking or cornering, which needs to be resisted by the neck and shoulder girdle muscles.

Weaver et al. (2006)'s research compared the number of Indy Racing League (IRL) racingdrivers who got brain injuries in crashes with a peak impact of Q50 vehicle G forces (G) to those who got brain injuries in crashes with a smaller impact. By looking at crash data from the IRL circuit from 1996 to 2003 to see if peak vehicle G could be used to predict brain injuries, they found that automobile accidents with peak vehicle G Q50 are much more likely to cause traumatic brain injuries than crashes with less impact.

Exposure to Carbon Monoxide

Most types of auto racing include a high risk of carbon monoxide exposure, particularly those that take place in closed cockpit racing championships like NASCAR, WEC, WTCC, and IMSA. Race vehicle exhaust gases and the electrical generators used in the pit and garage areas impair the quality of the air. In general, the number of cars on the track, the distance between cars, and the length of the race all affect CO exposure. Particular factors that encourage CO exposure are the practise of drafting, or driving nose-to-tail; extended engine testing and idling; using generators powered by gasoline in pit and garage zones; banking and high grandstands in small oval tracks and front-engine car configurations.

Gwinet al (2005) measured a race car's maximum carbon monoxide levels to be 202 parts per million (ppm). Peak CO levels were even higher in the pits (235 ppm) andin crew work zones close to the generator (835 ppm). Allen and White (2013) reported high levels of 200 parts per million in racing car cabins and 244 parts per million in the pits.All of these readings surpass the NIOSH-recommended maximum concentration of 200 ppm (1992).

Environmental carbon monoxide can acutely raise the concentration of carboxyhemoglobin in racing athletes' blood.After road course races, drivers' carboxyhemoglobin concentrations are often below 5% (Allen and White, 2013), much lower than the 10% threshold which indicates low-level carbon monoxide poisoning (Smollin and Olson, 2008). However, at the end of a short oval race, concentrations as high as 15% to 18% have been found (Walker, Ackland and Dawson, 2001). This is a moderate level of carbon monoxide poisoning, which can produce lethargy, headache, and weariness. Symptoms of severe poisoning due to carbon monoxide (>20%–25%) include confusion, loss of consciousness, and heart ischemia, while levels higher than 60% are lethal (Smollin and Olson, 2008).

Disproportionate exposure to carbon monoxide can create severe disturbances that hinder the task of operating a racing car, such as poor coordination, diminished accuracy in recognising a vehicle's location, longer times for reactions, and diminished multitasking abilities (Owen, King and Lamb, 2015). In addition to increasing perspiration and body temperature, carbon monoxide exacerbates the consequences of hyperthermia and dehydration on psychomotor capabilities. Dehydration involves fluid loss caused by the body's regular functions, primarily sweat and respiration. Insufficient fluid replenishment beforeand after rigorous physical activity leads to dehydration, which in turn may result in heat exhaustion, fatigue or heat stroke.

Injuries

The most common injuries among race car drivers are to the knee, shoulder, thorax, and ankle. Factors such as long-distance racing, more than 10 testing days per month, short-distance racing, and full-time employment were found to be linked to injuries of the knee, shoulder, thorax/rib, ankle, hand, forearm, neck, and wrist (Koutras et al, 2017).

Koutras et al (2017) also found rib fractures and shoulder fractures to be most frequent injuries, followed by cuts or contusions to the trunk and upper limb, fractured ankle and knee, the ligament injuries in the ankle and knee region, and ligament injuries in the aforementioned areas. Injury to the upper arm, elbow, forearm, hand, and lower leg area was linked to cart driving.Minoyama and Tsuchida’s research (2004) at Fuji Speedway documented injuries such as neck sprain, bruising and abrasions in head, chest, back and limbs.

INTERVENTIONS

Logging Sensory Inputs of Drivers

Not only are optimal hydration levels essential for motorsport athletes to sustain peak physical and mental performance, but they also contribute to safety and long-term physical wellbeing (Allen and White, 2013).Existing studies have found considerable variety in hydration levels, indicating that while some drivers drank enough during the race to compensate for perspiration loss, others did not(Australian Institute of Motorsport Safety, 2013). This implies that driver fluid intake must be measured in order to comprehend the association between hydration and the aforementioned stressors.

Examining the scientific literature reveals that respiration, carbon monoxide levels, heart rate, temperature, whole-body vibration and hydration,all contribute to the physical and mental tiredness of a driver in motor racing. In spite of this, no studies have utilised a technique that permits the determination of the cumulative impact of all stressors. Owen, King and Lamb (2015) have developed an electronic system that integrates and logs pertinent sensory input, customised for the driver and environment.

Accurate Noise Indicators

Existing research demonstrates the critical need for a comprehensive examination of the noise levels generated at the time of motorsport events in order to better evaluate exposure and collect data on the various methods to decrease noise to acceptable limits. Pascale et al. (2022) investigated noise levels during various motorsport events on a track in Battipaglia, Italy, and defined two noise metrics: the Lap Equivalent Level (LEL) and the Race Equivalent Level (REL) (REL). LEL describes the equivalent noise level on a specific recipient caused by a single-vehicle track lap, whereas REL describes the equivalent noise level generated throughout a race. The REL is likely to maintain its estimates during a race, indicating that it can be modelled using the average LEL and the number of cars competing in a race. On the other hand, the duration of the race provides information on the recipient's exposure duration to race noise levels rather than playing a significant role in the estimate of REL values. A comparison with existing metrics reveals that the performance of the proposed indicators is satisfactory. This method permits the comparison of the acoustic energy produced by a single vehicle (in the case of LEL) and a group of vehicles (in the case of REL) during events with varying durations.

Computer Aided Training Programs

The ever-evolving nature of racing, which combines the physical and intellectual talents of the driver with the engineering of the car, may explain the paucity of evidence-based training approaches in motorsports (Potkanowicz, 2019;Potkanowicz and Mendel, 2013).

The Vienna test system (VTS) is anautomated instrument for evaluating sport psychology-related characteristics in athletes, such as reaction time (RT), sustained attention, reaction time (RT), peripheral perception, stress reactivity, and temporal movement anticipation (Schuhfried, 2013). In numerous sports, including motorsport trainers, coaches, and practitioners utilize VTS to undertake cognitive testing (Ong, 2015). Horváth et al. (2022) recommended employing VTS to assess and/or cultivate cognitive skills pertinent to racing performance. They conducted a study to investigate the physiological and cognitive consequences of a 6-week reactive agility training program employing light-based stimuli on race car drivers. In a laboratory context, this program was meant to simulate the demanding physical and intellectual demands of automobile racing. During the maximal incremental cardiorespiratory test, heart rate at the ventilation, peak heart rate, gas exchange threshold, and relative maximal oxygen consumption rose as a result of positive alterations generated by the training intervention. Finally, the race car drivers executed the objective of reactive agility with enhanced performance and reduced reaction time.

Thus, Horvaith et al. (2022) concluded that a short and convenient training program has the capacity to elicit positive effects on a few physical and cognitive performance indicators and may have the capacity to contribute to the physical and mental preparedness of auto racing drivers.

Fatigue Detection

Ansari et al. (2022) investigated the automatic diagnosis of racing drivers' cognitive fatigue based on upper body posture dynamics by creating a semi-supervised method for determining the cognitive fatigue patterns of driver posture. By applying an unsupervised Gaussian Mixture Model (GMM) clustering to acceleration data signifying the driver's head, neck, and sternum procured in a simulated driving through a motion capture suit, the optimal groups of the most identical and correlated time-series data of driver upper posture were identified. Then, they created an algorithm for automatic labeling and applied unique supervised machine learning classifiers to detect driver weariness. Their findings indicate that the suggested semi-supervised technique outperforms existing state-of-the-art systems in reliably diagnosing cognitive tiredness patterns and successfully recognizing various driving postures with accuracies more than 90 percent.While Ansari et al (2022) used a number of sensors fitted on the driver's body, in the real-life driving experience, this can be substituted with other technologies such as smart clothes or embedded driver seatsensors.

II. Conclusion

This study provides an in-depth review of the existing literature on the evolution of motorsports, the major physiological effects of motorsport participation on race drivers and some interventions that may help mitigate these effects.

It reviews existing literature on the unique health risks linked with motorsports and developing measures to prevent these risks. The body of research demonstrates that driver athletes face a variety of physiological difficulties, such as physical and noise fatigue, thermal stress, cardiovascular stress, high levels of g-force, exposure to carbon monoxide and injuries. It also reviews literature that presents safety measures and technological interventions such as systems for logging sensory inputs of drivers, accurate noise indicators, computer aided training programs and automatic fatigue detectionto overcome these effects of motorsports on drivers.

This paper adds to the current literature on physiological effects of motorsports on racing drivers, and is a useful resource for students, researchers and medical professionals in the field of motorsports. In terms of practical implications, this paper can help racing car drivers, motorsports events organisers, team owners and motorsports medical teams to better understand the physical challenges faced by drivers and focus on improvements that can add to driver safety and well-being.

Future research could focus on specific physiological effects in depth and explore the feasibility of the proposed interventions. Comparative studies on the extent of damage caused by different forms of motorsports may also be conducted.Large-scale studies that precisely evaluate the frequency and prevalence of various injuries may reduce the current difficulties associated with the medical management of injuries in motorsport.

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Shlok Lavsi. “The Health Effects of Motorsports on Racing Car Drivers: A Review.” *IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)*, 22(3), 2023, pp. 31-38.