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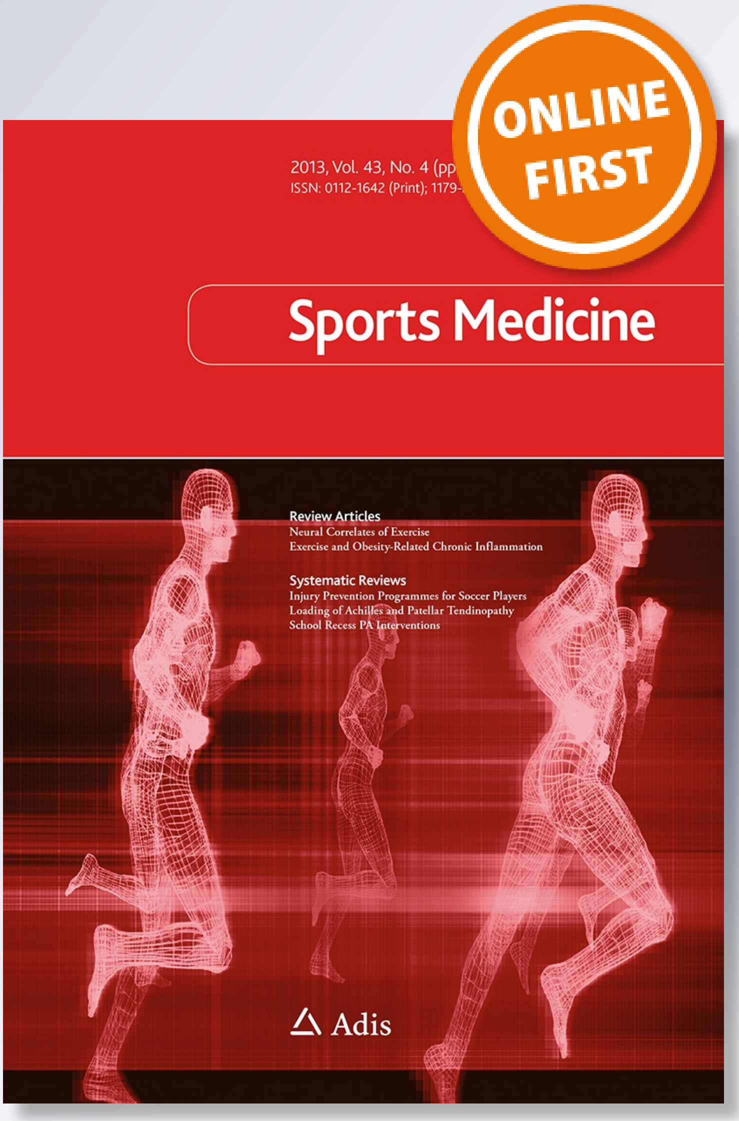
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REVIEW ARTICLE

The Case for Driver Science in Motorsport: A Review and Recommendations

Edward S. Potkanowicz · Ronald W. Mendel

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Abstract When discussing sports and the athletes who participate in them, it has long been recognized that fitness is a prerequisite for optimal performance. The goal of training to improve fitness levels in athletes is ultimately to minimize the stress that the body experiences during competition. When it comes to the topic of racecar drivers, however, drivers and their trainers have largely been left to their own devices to figure out the stressors and the areas of specific training focus. Unfortunately, racecar drivers have battled the stereotype that they are not athletes, and with little regard for them as athletes, drivers are seldom the focus of scientific research related to their performance. Like the cars they drive, driver-athletes are complex, but from a physiological perspective. However, unlike the cars they drive, driver-athletes have not been examined, evaluated, and tweaked to the same degree. The purpose of this review is two-fold: first, by examining the available literature, to make the case for new research into the driver's role in the driver-car system (i.e. driver science) and the stresses experienced; second, to make the case for more extensive use of microtechnology in the real-time monitoring of driver-athletes. With the miniaturization of sensors and the advent of portable data storage devices, the prospect of quantifying the stresses unique to the driver are no longer as daunting, and the relative impossibility and difficulties associated with measuring the driver-athlete in real-time no longer need to be as challenging. Using microtechnology in the assessment of the driver-athlete and with a more public discussion and dissemination of information on the topic of driver science, the scientific community has the opportunity to quantify that which has been largely assumed and speculated. The current article will offer the following recommendations: first, rather than examining a singular physiological stressor, to examine the interaction of stressors; second, to examine variables/stressors that are more representative of the changing driver demographics; third, to measure drivers in real-time during actual race events; lastly, to work to develop training programs that more accurately apply to the driver and the stresses experienced. In uncovering this information, there is an opportunity to contribute to racing becoming that much safer, that much more competitive, and that much more comprehensive for the driver, the team, and the sport.

1 Introduction

For some time, racecar drivers have battled the stereotype that they are not athletes. While efforts have been made to correct this misconception, the viewing public still looks at driving a racecar as nothing more than "turning left." With little regard for them as athletes, drivers are seldom the focus of scientific research. For all of the preparation that was done for this article, the authors could not find a published reason as to why drivers are not examined more extensively. Rather, efforts go toward analyzing and improving the car and related equipment. With the high-priced world of motorsports being driven by technology and engineering, drivers are subjected to greater physiological stress than ever before. Therefore, to not examine the driver in the driver-car system (i.e., that singular unit of

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car and driver) is to ignore a significant part of the total system. While practically every system of the car is monitored, little is known about the human controlling the car and the conditions he or she is experiencing. The purpose of this article is to examine the work that has been done to date examining the racecar driver and the stresses experienced. In doing so, two objectives will be achieved. First, the authors will make the case for "driver science" and for additional and more comprehensive research into the driver's role in the driver-car system. Second, the authors will make the case for the more extensive use of microtechnology in driver monitoring in an effort to help quantify the actual stressors that a driver experiences. The overarching goal is to use the data gathered from driver-related studies to develop meaningful training interventions for the driver-athlete in an effort to improve driver performance and to make motorsports safer.

To that end, the following databases were searched from inception to October/November 2012: MEDLINE, PubMed, and Sports Discus. The literature search used the following terms, with synonyms and closely related words: "driver performance," "motorsport performance," "open wheel," "Formula 1," "racecar driver and body temperature," "racecar driver" and "driver safety." The authors also examined popular sports magazines (e.g., Road and Track and Sports Illustrated) and motorsport and industry websites for anecdotal evidence.

2 The Driver-Athlete

The word "athlete" is derived from the Greek word "athlein," which means "to contend for a prize." Further, the word "athlein" is derived from the Greek word "athlos," which means "feat." Merriam-Webster defines the athlete as "a person who is trained or skilled in exercises, sports, or games requiring physical strength, agility, or stamina" [1]. To apply this definition to the traditional athlete (e.g., football and soccer) is a simple enough task. Is what they do a feat? Do they, as their name implies, compete for a prize? Yes. As such, society bestows upon them credibility, recognition, and regard. Can the same be said of the racecar driver?

Using Merriam-Webster's definition, do the racecar drivers demonstrate and possess the characteristics of the athlete? Are the drivers skilled? Do they possess physical strength, agility, and stamina, and do they contend for a prize? What makes this assessment difficult for the average person is that there is no obvious or visible perception of effort. During a football game, the spectator sees the hit. During a soccer game, the spectator sees the player bend the ball during a shot on goal. In motorsports, the spectator watches the car as it moves around the track. The spectator does not see what the driver is really doing or experiencing. Even with in-car cameras, the effort being put forth by the driver seems minimal to the spectator. Further, while few people can bend a soccer ball or throw a 60-yard pass, almost everyone drives. This makes what the driver is doing seem very "everyday" and somewhat lacking in athleticism. Seldom, though, does the everyday driver put forth as much effort or encounter as many obstacles as the racecar driver. In fact, the argument could be made that even though drivers do not run and jump during competition, they undergo similar, if not greater, physiological stress than traditional athletes [2–5]. For this reason, the argument can be made that to compare the racecar driver to the traditional athlete is actually an unfair comparison. What traditional sport involves: (1) high speed and the multi-tasking nature of driving (braking, steering, etc.); (2) extended and continual periods of performance (i.e., 2–3 h); (3) persistent thermal stress; (4) repetitive G-loading; (5) physiological, psychological, and emotional stress; (6) the ever present risk of death? In motorsports, there are no timeouts; there is no half time; there is no coming out of the race for a drink of cold water. Even though what the driver is doing may not look particularly athletic to those unfamiliar with challenges of motorsports, he or she must possess great physical strength to counter the repetitive G-loading and to turn the steering wheel in this high G environment (e.g., 800 G-loading turns in the course of the Indy 500). He or she must possess sufficient agility and judgment in order to move the steering wheel with great accuracy and speed all while traveling, in some cases, at over 200 miles per hour. At the same time, the driver must concentrate on the variances of the course (i.e., bumps, chicanes, and changing track conditions), avoid making contact with other drivers, and manage the data being displayed on the steering wheel (e.g., Formula One). The driver must do this in conditions of limited mobility and vision due to the safety restraints and seat position. The driver must also possess the stamina required to maintain this level of performance for an extended period of time without a break. While the spectator may not see all that the driver is doing, while there may not be a visibly obvious output of effort, the racecar driver is certainly demonstrating, and possesses, the characteristics of the athlete. If the driver performs well, then he or she will have certainly demonstrated an exceptional feat and will be rewarded with a prize, just like the traditional athlete.

3 How Science has Helped the Traditional Athlete

When discussing sports and the athletes that participate in them, it has long been recognized that fitness is a prerequisite for optimal performance. What was not so obvious initially was the fact that not all athletes were the same and could not be trained the same. The more recent past has focused on sport-specific training for athletes so that their training could be optimized into greater transfer to their sport; this is the Principle of Specificity. The Principle of Specificity states that training should be relevant to, and appropriate for, the athlete's sport in order to produce/elicit the desired training effect [6].

The goal of training to improve fitness levels in athletes is ultimately to minimize the stress that the body experiences during competition. Because all athletes and sports are different, sport-specific training has become very popular. In order to train specific to a sport, one must know the demands that are placed on the body while actively engaged in that sport. This allows for recommendations to be made for the safe and effective training of the athlete. For example, in 2007 (revised 2011) the International Association of Athletics Federations released specific nutritional recommendations for the events and conditions that the athlete may participate in or encounter [7]. Recommendations for the traditional athlete are the result of investigations examining the physiological stress of performance. Historically, these investigations have been laboratory based. However, with the introduction of new and smaller technology, many more of these investigations measure the athlete in the field [8–11]. An example of this technology can be found in the Cosmed K4 b^2 (Cosmed USA, Chicago, IL, USA). This particular unit reduces the metabolic cart commonly found in many exercise physiology laboratories down to a wearable unit that can provide the same information in the field [12, 13]. Likewise, the ubiquitous wearable heart rate monitor provides valuable information to the athlete and the trainer in the field. Technology has made the acquisition of data easier and more sport specific. Trainers can take full advantage of the principle of specificity by seeing exactly how the athlete responds, adapts, or improves.

4 Science and the Driver-Athlete

When it comes to the topic of racecar drivers, however, drivers and their trainers have largely been left to their own devices to figure out the stressors and the areas of specific training focus. While trainers try to simulate the racecar and race event environment with their training regimens (e.g., hot yoga, loaded steering wheel resistance training, reaction testing, and training), without quantifiable data of the driver's experience, these regimens do not take full advantage of the principle of specificity. Klarica [14] even suggested that "sports medicine is seriously underused." Additionally, Lighthall et al. [2] noted that while some work has been conducted by independent laboratories and consulting agencies, little of this work has ever found its way to refereed journals or been made available to the public. In most cases, anecdotal reporting has been the foundation on which training has been based. Historically, racecar drivers often ignored the idea that specific training was necessary to perform optimally. Jutley [15] suggests that it was the collapse of Nelson Piquet on the podium following the Brazilian Grand Prix in 1982 that led to the governing body of motorsports finally looking into driver performance and fitness. The growing emphasis behind driver fitness was not necessarily about driving faster, but rather, safer.

While some have advocated and written about the need for driver fitness, much of what is suggested is based in generalities [2, 3, 14, 15]. Little is known about the actual stress experienced by the driver during the course of a motorsports event. Beyond the individual stressors (e.g., increased heart rate, increased core body temperature, or increased G-loading), what is even less well understood is the way that the individual stressors interact with one another and the effect of those interactions on the driver-athlete. For example, while increases in driver heart rate and body temperature have each been demonstrated empirically, there are no published investigations of their interactive effect [3, 16–18].

This is not to say that nothing has been done in the area of driver science. However, those in the scientific community who have published studies of the individual stressors experienced by the driver-athlete have typically conducted investigations during off-season testing, have used modified equipment, have used measurement techniques that would not typically be approved by sanctioning bodies of motorsport, or have not actually looked at the athlete but rather the racecar [3, 4, 16, 19]. For example, Küçükdurmaz [20] offers that the pedals of Formula One cars are particularly stiff and require "high strength of the lower extremity." As such, the author recommends a "well-balanced exercise of feet, legs, and hips." However, what is not offered is what the driver is actually experiencing. While the pedal may offer 80 kg of resistance, the driver must actually exert more than 80 kg of force to move the pedal. And in the case of a 2–3 h race, he or she must do this repeatedly. This example measures a car variable, not a driver variable. How much force is the driver generating? What is the impact of protracted heat exposure on his or her capacity to generate force? Additionally, there is no resulting recommendation for the driver that addresses exactly what to do during the "well-balanced exercise of feet, legs, and hips." For example, with repeated pedal operation during the course of a race, what recommendations are given to combat the muscular fatigue? Should the driver-athlete train aerobically or anaerobically? The current body of research is unclear on exactly what a driver should do.

In the following sections, the authors will review the work that has been done and make the case for new investigations in the area of driver science and for the role of burgeoning technology.

5 The Stressors Unique to a Racecar Driver

Like the cars they drive, driver-athletes are complex, but from a physiological perspective. However, unlike the cars they drive, driver-athletes have not been examined, evaluated, and tweaked to the same degree. Our current understanding of the driver (as part of the driver-car system) suggests that the primary physiological stressors experienced by racecar drivers are increased and sustained heart rates, muscular effort, increased body temperature, and G-forces [16, 20–23]. Further research may also identify additional areas of investigations.

5.1 Heart Rate Response

Elevated and sustained heart rates are a hallmark response to physical activity. Motorsports is no different, as racecar drivers have demonstrated the same type of heart rate responses during practice and competition. Although one might think that the increase in heart rate is the result of a single influence (i.e., physical stress), a single source of the chronotropic increase has not been found. Rather, two primary factors are at play. The first is directly related to the physical work requirements necessary for competing in motorsports. The second factor is an increase in sympathetic nervous system output and the hormonal influences derived from the anxiety, anticipation, and competitive nature of the sport [19].

As far back as 1967, the literature speaks of the heart rate response of racecar drivers being elevated [24]. Similarly, Bertrand et al. [16] identified heart rate as a significant stressor during participation in motorsports. In 1987, Schwaberger [19] recorded average heart rate values of 174.3 beats per minute (bpm), a value corresponding to 90 % of maximal heart rate following exhaustive ergometry. As recently as 2007, Brearley and Finn [18] reported heart rates of greater than 170 bpm in V8 Supercar drivers.

While increases in heart rate may be a hallmark response, what is perhaps more interesting is the interaction of heart rate with other physiological variables. As noted earlier, there are no published studies of the interactive effect among variables. For example, heart rate and exercise intensity share a proportional and linear relationship [6]. As exercise intensity increases, heart rate continues to increase in proportion to exercise demand until the exercise reaches maximal intensity. However, during times of persistent physical activity and heat stress, when the cardiovascular system is challenged to provide for both the exercising muscle and thermoregulation, there is a disproportional increase in heart rate even though there has been no increase in exercise intensity; this is known as cardiovascular drift [6, 25]. Evidence of this response was noted as long ago as 1956 when Ladell and Watkins [26] noted an increase of 25 beats for every one-degree increase in body temperature. Should this condition persist, the athlete is at risk for the early onset of fatigue and eventual performance deficits [27–30]. For the driver-athlete, given the nature of the sport, this can be a particularly dangerous proposition. Therefore, quantifying the individual stressors as well as understanding the interactions between them is the direction that the burgeoning area of driver science needs to head.

A second example is the impact of dehydration on cardiovascular function and thus physical performance. Armstrong [31] offers that, regardless of the environmental temperature, acute dehydration reduces maximal oxygen uptake. Armstrong [31] also offers that the larger the fluid loss, the greater the loss in aerobic capacity. Greenleaf [32] suggests that body water losses equivalent to 4 % of total body weight result in a 20–30 % loss of physical work capacity. Examining the literature, it is not uncommon to see fluid losses in drivers reported in the neighborhood of 1.0 l per hour [16, 18, 33]. From a functional perspective, this relates directly to a reduction in endurance capacity resulting from changes in cardiovascular function (e.g., increased heart rate and decreased cardiac output) [34]. In the end, while we know that a driver-athlete's heart rate increases in response to the stress of competitive driving, what is less well known is what happens to that same heart rate response after an extended duration race in the face of long standing hypohydration or dehydration? Also, while drivers may train aerobically in an effort to be a fit as possible, do the recommendations for aerobic training address the effect of the dehydration on heart rate response or the effect of thermal stress on heart rate response?

5.2 Muscular Effort

There was a time when driving a racecar was not considered to be particularly "physical" [35]. That misconception is continually changing as more is learned about what exactly a driver does and experiences while in the car. What the driver-athlete does is so much more than the old joke about turning left. He or she must repeatedly move a steering wheel that, in some cases, has no power steering. Regardless of the type of steering, the exhaustive repetitiveness of steering wheel input would be of particular interest in an investigation of the muscular efforts associated with driving a racecar. Besides steering, the driver must operate the pedals of the car, each of which has its own resistance and number of times that it is depressed in the course of a race. Add to these examples the repetitive G-loading (negative and positive) and the effort that the driver must put forth to maintain his or her position in the cockpit against that load. Simultaneously, he or she must work to keep the head, clad in a helmet with a combined head-helmet weight of approximately 6.5 kg, in the proper driving position [22].

Evidence of this muscular effort can be found in the work of Jacobs et al. [4]. In this study, the authors compared the physiological responses of drivers to road and oval courses. Their findings demonstrated higher oxygen consumption and heart rates during road course testing compared to an oval speedway, although the absolute driving speeds on the road course were slightly more than half of the speedway speeds. The authors speculated that, while there are potentially several different explanations for these responses, the primary explanation might be related to the muscular work differences. They suggest that the increase in oxygen consumption and heart rate reflects an increase in energy expenditure above baseline. The stable body position of the driver is established primarily by isometric contraction of the neck, abdomen, and legs. Therefore, the increased energy requirements are most probably related to the increased muscular activation required to maintain the driver's position in the car.

Similarly, Schwaberger [19] demonstrated statistically significant increases in blood lactate levels following driving challenges in a group of 20 driver-athletes. The authors reported an increase in lactate from mean resting levels of 1.56 mmol/L (±0.39) to a mean of 3.27 mmol/L (±1.40) following the driving challenge. The author attributes these increased lactate levels to "the high emotional stress" and "a certain dynamic and static muscular component."

Ebben and Suchomel [36] approached the topic of muscular effort from a more subjective perspective. The authors interviewed 40 stock car drivers from 27 different states in the US in an effort to assess the physical demands, injuries, and conditioning practices. As it relates to muscular strength, the authors reported a significant negative correlation between "track points standings" and length of resistance training sessions. Additionally, the authors identified, via participant self-report, upper body strength as the most important physical demand. Additionally, participants in the study reported shoulder fatigue as the most common form of muscle soreness experienced after a race event.

In a 2012 RoadandTrack.com interview, IndyCar driver Dario Franchitti related how he asked his race engineers to quantify the muscular effort he puts forth during a race event [37–39]. Using the on-board data acquisition system, the engineers determined that during each of three major braking efforts at the Mid-Ohio Sports Car Course, Franchitti generated 1,375 pounds per square inch (96.67 kgf/cm^2) of (brake) line pressure. When they factored in the motion ratio of his brake pedal, they were able to calculate that Franchitti was applying 135 pounds (61.24 kg) of force to the brake pedal each time. When the engineers examined the effort put forth by their driver to steer, they calculated an effort equivalent to 35 pounds (15.88 kg) of twisting force each time he turned the wheel. For the duration of the race, which includes 13 turns, the engineers reported that their driver would have done the equivalent of 1,105 repetitions.

These studies, and the anecdotal reporting of RoadandTrack.com, represent the few that have addressed the role of muscular strength directly in the car in motorsports. And even these findings were not direct measurements of the muscular effort put forth by the driver, but rather estimations based on the findings of related physiological systems, functions, or interactions with elements of the car itself. While some have reported on the muscular characteristics of driver-athletes, these too have been laboratory based and did not include actual driving, but rather simulation or driving-like analogs [5, 21, 40, 41].

5.3 Increased Body Temperature

The typical driver-athlete wears a multitude of safety garments. These would typically include a fire suit (one to three layers thick), fire resistant undergarments, a balaclava, fire resistant boots and gloves, and a helmet. As a result of these safety measures, what is left of the driver exposed to the environment is what the spectator sees peeking out of the visor. The driver then places him or herself into a vehicle, which has either little or no circulating air. The layers of protective clothing and the enclosure of the cockpit create numerous microenvironments, each compromising the driver's thermoregulatory ability [4]. Adequate thermoregulation requires exposure to the environment and a gradient (i.e., either a dry heat exchange gradient or a water vapor pressure gradient). As was mentioned, the part of the driver's body that is exposed to the environment is not much more than his or her eyes, assuming the visor is up. This presents a problem. Although all of the safety equipment is necessary, under the physical stress of driving, it's not long before the driver finds him or herself subjected to a severe, and often an uncompensable, heat stress. Add to this the compounding impact of repeated muscular effort, excessive humidity, and dehydration and the problem is not only disconcerting, but also potentially dangerous. Anecdotal evidence of this danger, at least for the driver, can be seen in the collapse of Formula One driver, Nigel Mansell, as he attempted to push his John Player Special Lotus across the finish line during the 1984 Dallas Grand Prix. Similarly in 1982, Nelson Piquet, having just won the Brazilian Grand Prix, passed out while standing on the podium.

In sports, the impact of excessive body temperature on human performance has been well documented and has been shown to have a number of negatives outcomes [31, 42, 43]. In contrast, the effects of increased body temperature on the driver-athlete and performance are not as well documented. Although few empirical studies have examined this issue, some have mentioned the need for investigation. As far back as 1972, Falkner [35] questioned whether the issue of the cockpit environment and the hot conditions drivers are exposed to warrant further or new investigations. In 1987, Jareño et al. [44] wrote to the editor of the British Journal of Sports Medicine with the intention of alerting readers to the risk of thermal stress in motor-car prototype racing drivers. As was mentioned earlier, Bertrand et al. [16] identified "raised body temperature" as one of the physical stresses experienced by the driver-athlete. Concerned about the impact of heat stress, Rodrigues and Magalhães [45] investigated the role of hyperthermia in the 1994 death of Formula 1 driver Ayrton Senna, but concluded that Senna's death was not the result of uncompensable heat stress. Jacobs et al. [4] suggested that given the environment that drivers perform in, the heat stress they are exposed to, and the likelihood of developing uncompensable heat stress, future research in this area is warranted. As evidence of this need, Wyon et al.'s [46] work was cited, documenting deterioration in hand-eye coordination in passenger car drivers with an increase in core body temperature of as little as 0.8 °C. The authors go on to say that not only is there a paucity of "publicly available data regarding the professional racecar driver," but that the reason for this lack of scientific information is that much of it is never published by the independent laboratories and/or consultants who conduct it [4]. Given that the steering wheel of a current Formula 1 racecar has more than 20 buttons, some with more than one function, clarity of thought and judgment, as well as response time and accuracy, are clearly essential. The effect of increased driver body temperature on various aspects of performance seems like a worthy candidate for further investigation and publication.

Some within the scientific community have attempted to quantify the thermal stress experienced by the driver-athlete. Collins [47] was contracted by the National Aeronautics and Space Administration to assess the physiologic responses of racecar drivers. Although body temperature was measured, it was not a main focus of the project and thus not reported in any meaningful detail. Additionally, body temperature was assessed orally, which is known to be an inaccurate measure of core body temperature given the influence of respiratory air movement. What is particularly interesting about Collins' work is the mention of cooling suits provided by the Hamilton Standard Company as a way to address the issue of thermal stress. The mention of these suits, used in a race in Austin Texas in 1964 some 50 years ago, demonstrates that thermal stress was a concern even then.

Brearley and Finn [18] examined the thermal response of four V8 Supercar drivers during short- and long-course races. Using ingestible core probe technology, the authors reported an average post-race core temperature of 39 °C (102.2 °F). This was an increase from the average pre-race temperature of 37.7 °C (99.86 °F). Using simulated driving within an environmental chamber, Walker et al. [17] examined the impact of heat and carbon monoxide on driver performance. With the environmental chamber set to mimic a NASCAR event (i.e., 50 °C ambient temperature and 10–12 % carboxyhemoglobin levels), drivers demonstrated significantly greater sweat loss and core temperature change than when the driver was exposed to the heat-only environment.

As is evidenced by the three studies mentioned here, very little work has been done examining the thermal stress experienced by the driver. If similar studies have been conducted, they have not been published and/or made available to the scientific community.

5.4 G-Forces

G-force represents the acceleration that a mass (in this case the driver-athlete) experiences in a given situation. This force can be both positive and negative and can occur on more than one axis [i.e., Gx (front-to-back), Gy (side-to-side), or Gz (head-to-toe)]. Furthermore, G-Force can be a significant force to contend with from a human performance perspective. Former Formula One driver David Coulthard related it this way: "Your upper body must be strong enough to survive the stress of 5 G, and when you brake at the end of the straight it feels like a sledgehammer has hit your back" [48].

There is scientific evidence on how much G-force the human body can tolerate. For example, when exposed to positive Gz forces, it becomes difficult to breathe as the lungs are pulled down and emptied of air [49]. Further, a greater cardiovascular effort must be put forth in order to pump blood to the brain. In the presence of positive Gz forces, blood is pulled away from the head, regardless of how hard the heart works [49]. Regarding circulatory issues, the eyes start having trouble from a circulatory and delivery perspective around 2–3 G [50]. First, peripheral vision is lost, which creates the tunnel vision effect. If the condition persists, vision continues to degrade it, then is lost completely and a blackout occurs. Regardless of the environment or setting, persistent and excessive G-loading can be problematic from a performance perspective.

One of the best examples of science being used for the benefit of the driver-athlete revolves around G-forces and the cancellation of the 2001 Championship Auto Racing Teams (CART) Firestone Firehawk 600 at the Texas Motor Speedway. Following two unexplained crashes during practice and drivers reporting episodes of dizziness and vertigo, being sick to their stomachs, and being unable to stand after exiting the car following practice, the medical safety staff began to suspect that the drivers were experiencing symptoms of excessive G-loads [51]. Data pulled from driver Paul Tracy's in-car data acquisition system confirmed the suspicion and showed that Tracy had experienced in excess of 3.5 Gs vertically and 5.5 Gs laterally [51]. The discovery that the drivers were experiencing a combination of excessive vertical and lateral G-forces, and in the case of one driver, G-induced loss of consciousness (G-Loc), CART determined that it was unsafe for the drivers to compete [51]. It was determined that the drivers were experiencing the very high combined G-loads because of their high on-track speed (all but two cars had average speeds of over 230 mph in practice) and the banking of the speedway (24° in each of two turns) [51, 52]. The decision to cancel the race was based on the empirical data from Tracy's in-car data acquisition system, but also from the anecdotal reports of drivers. This event and its outcome represent the value of empirically derived data related to the driver and motorsport safety.

6 Recommendations

The purpose of this article was two-fold: first, to make the case for new research and investigations into the driver's role in the driver-car system (i.e., driver science) and the stresses experienced; second, to make the case for more extensive use of microtechnology in the real-time monitoring of driver-athletes.

Regarding the first objective, examining the literature, it becomes evident that there is a paucity of information available to the scientific community regarding the stresses that the driver-athlete experiences. This singular point is by itself sufficient evidence to make the case for the need for new and additional work. Additionally, there are little more than anecdotal data on how to best prepare a racecar driver for the physical rigors of the cockpit. If empirical investigations have been conducted by independent laboratories or consultants, that information is not being published widely in academic journals.

Not to study the driver is to ignore a very important part of the driver-car system; not to have empirical data available about what the driver is experiencing in the cockpit is analogous to ignoring all the data related to engine performance and then expecting the engine to run well or to last the whole race. In order to tune the engine to its fullest potential, the engineer needs every possible piece of data. Likewise, to prepare the driver for the safest and most productive outcome while in the cockpit, those responsible for driver preparation must have as much relevant information as possible.

Frank Williams, principal of Williams F1 Racing, said of Ayrton Senna:

> "Ayrton is arguably the best driver available, the best driver currently racing. The team is geared to being successful. All our partners, investors, sponsors expect that of us. And Ayrton is therefore the best piece of equipment, if you'd like, you could put in the machine to deliver to our requirement" [53].

Using this comparison of the driver as a piece of equipment, if the driver is to function at the highest level, then, as with any other piece of equipment, those who are responsible for it need to know as much about it, and its variations, as possible in order for it to function at its fullest.

Speaking specifically of the variations in driver-athletes, there must also be new consideration for evolving driver demographics. Historically, racing has been populated by men. However, in recent years, numerous series, both developmental and professional, have seen an increase in the number of female drivers. What little is known about the impact of the stressors on the male physiology is magnified when the discussion turns to the female driver. To not address gender-specific issues related to racing performance is to ignore a burgeoning driver-athlete population. Similarly, with drivers coming into developmental and professional series at younger ages and with drivers competing into their 40s, examining issues related to the influence of age on driving performance would be of value. Fundamental to the argument is that understanding the stresses that the driver-athlete experiences makes a safer and better driver.

Regarding objective two, the relative impossibility and difficulties associated with measuring the driver-athlete in real-time no longer need to be as challenging. With the miniaturization of sensors and the advent of portable data storage devices, the prospect of quantifying the stresses unique to the driver are no longer as daunting.

A good example of this new approach can be found in the work of Beaune et al. [54], examining the energy cost of racecar drivers using actimetry. The authors used the Armband Sensewear Pro® (BodyMedia, Inc., Pittsburgh, PA, USA) to measure the energy expenditure in eight driver-students during multiple bouts of driving. The authors used technology that is relatively non-invasive, does not interfere with the driver's actions, and produced meaningful data that can be used in driver training and preparation.

This is not to say that there aren't challenges to this novel technological approach. For example, what makes the assessment of heart rate challenging is the concern for driver safety. As was mentioned earlier, the heart rate monitor has been available for years. Some drivers have even worn them during race events. What makes this assessment particularly problematic is the burn risk associated with wearing a monitoring device made of a material that can melt on the skin in the event of a fire. Another example would be the radio transmitter (CorTemp®, HQ Inc., Palmetto, FL, USA) used for the assessment of body temperature [18]. There are some sanctioning bodies that would not allow the use of such a device because it could prevent the use of some medical interventions in the event of a crash. The manufacturer of the ingestible probe lists as one of its contraindications, "any subject who might undergo Nuclear Magnetic Resonance Imaging or Magnetic Resonance Imaging scanning during the period that the CorTemp® Core Body Temperature Sensor is within the body" [55].

The challenges of using technology in the cockpit are, first and foremost, the safety of the driver. Second, the new technology must be accurate. Recommendations for any intervention must be based on reliable and valid data. Thirdly, the technology must not interfere with the driver in any way. And lastly, the new technology must be both small (to minimize weight concerns) and rugged (to tolerate the cockpit and racing environment). Lighthall et al. [2] encountered some of these same difficulties when attempting to assess driver heart rate response. Data collected during race events exhibited significant electromagnetic interference (EMI), which resulted in inconsistent data. The authors resolved the EMI problem by wrapping the recorder in heavy gauge aluminum foil. Technology has progressed significantly since 1994.

Given these advancements and the opportunity to expand the knowledge base, the following recommendations are offered. First, rather than examining a singular physiological variable, examine the interaction of variables. For example, measure the impact of increased body temperature on heart rate response. Second, examine variables that are more representative of the changing driver population. For example, examine gender- and age-related differences. Third, measure drivers in real-time during actual race events. For example, make physiological data available in the pit box that can alert the team when the driver is likely to make a mistake because of fatigue. Additionally, using the data gathered from races, develop laboratory-based simulations representative of the driver's actual physiological response rather than anecdotal reports. Lastly, work to develop training programs that more accurately apply the principle of specificity.

7 Conclusion

During an interview for a 1992 documentary, three-time Formula One world champion Ayrton Senna spoke of the importance of physical training this way:

"You can drive a Grand Prix car whether you are fit or unfit but for how long you can drive, how precise, how consistent you can drive under stress, under high temperature, the difficult conditions during race is another thing. You know that's gonna be tough, you know you gonna feel tired, gonna have some pain, you gonna lose a lot of liquids. But you know you can do it as good as anybody if not better if you are well trained, well fit. So, if you are not fit your concentration just tends to go gradually away during a race" [56].

Many driver-athletes since Senna have commented anecdotally on the physical challenges of driving a racecar. Some have even expressed an interest in knowing just exactly what they're experiencing in the cockpit [37–39]. However, as was mentioned earlier, drivers and their trainers have largely been left to their own devices to figure out areas of specific training focus. With the introduction of microtechnology into the assessment of the driver-athlete and a more public discussion and dissemination of information on the topic of driver science, the scientific community has the opportunity to quantify that which has been largely assumed and speculated upon. Providing quantifiable data through additional research will help to validate the driver as an athlete. In uncovering this information, the scientific community has an opportunity to contribute to racing becoming that much safer, that much more competitive, and that much more comprehensive for the driver, the team, and the sport.

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