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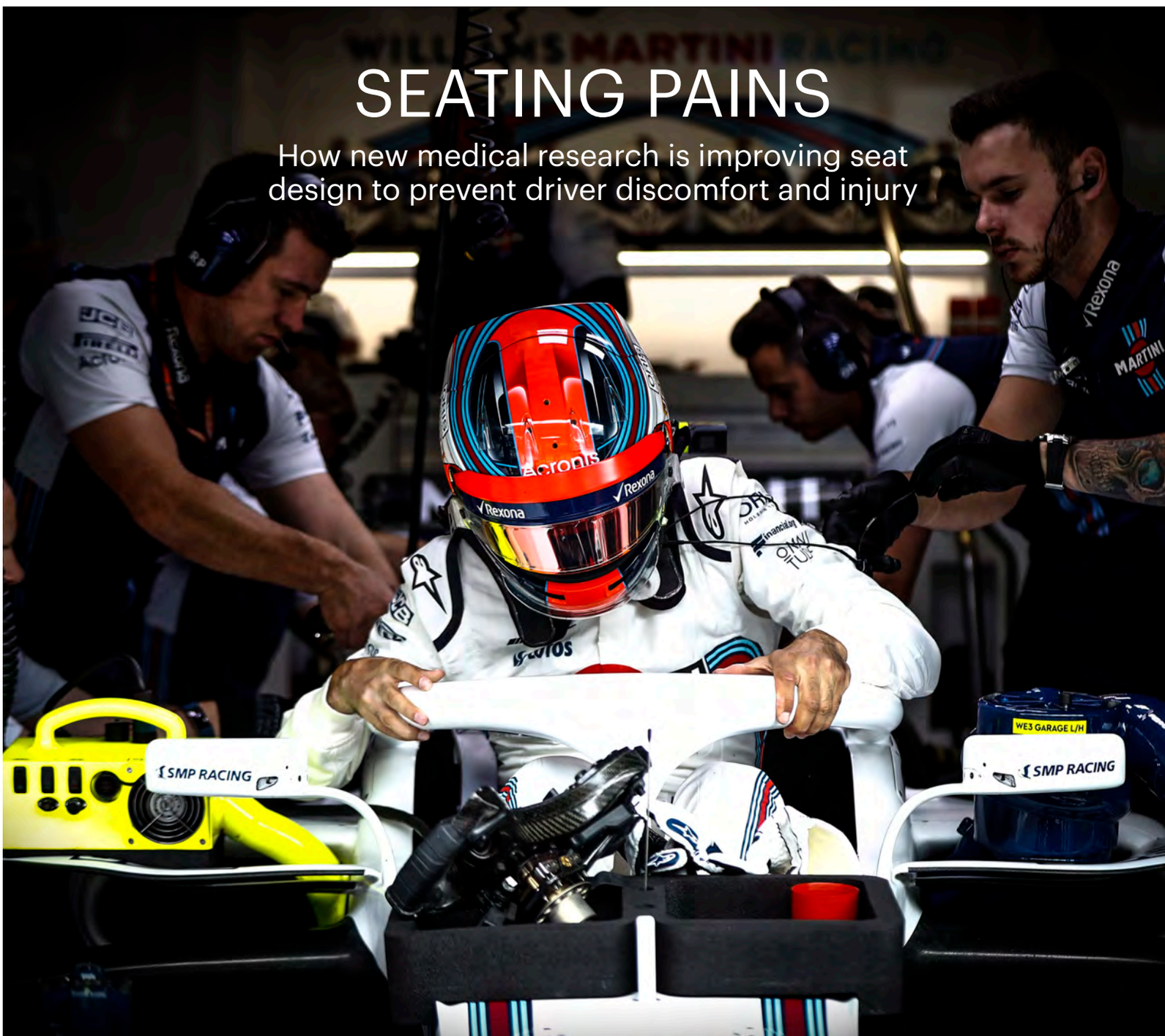

SEATING PAINS

How new medical research is improving seat design to prevent driver discomfort and injury

AUTO+MEDICAL

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I am thrilled to join the editorial board of this prestigious publication that reaches the medical community dedicated to motorsport around the world.

The cover of this edition draws our attention to the seats of racing cars, discussing their importance concerning safety and how technology is being used for this purpose. We must bear in mind that the current concept of safety in racing cars must come from inside out, that is, it should focus on the padding around the driver and the seat, so that the energy dissipation generated during an accident is transferred as little as possible to the driver, mitigating the injuries caused.

In the case of prototypes competing in endurance events, as mentioned by Alex Wurz, shorter drivers have their safety compromised with the insertion of foams which allow a better position for driving, but do not maintain the same restrictive protection of the trunk, pelvis, shoulders and sometimes even of the lateral protection of the head. In short, an article that raises many questions that are being investigated to improve drivers' safety.

Dr Naomi Deakin sets an example for all the doctors working in motorsport, for her dedication and perseverance, joining her medical training to her recreational interests, thus adding value to the safety of our sport. It is with great merit that Dr Deakin was awarded the Watkins Scholarship, giving a sequel to a work initiated by Prof Sid Watkins who sought to understand and minimize severe traumatic brain injuries.

Enjoy this edition.

Dr Dino Altmann
Deputy President, FIA Medical Commission

GLOBAL NEWS

SAFER barriers have been a key safety feature at ovals

AWARD FOR LIFESAVING SAFER BARRIER

A team of researchers behind the Steel and Foam Energy Reduction (SAFER) barrier has been honoured with the Dr John Melvin Motor Sport Safety Award.

Leading figures in highway safety research collected the award on behalf of the Midwest Road Safety Facility Team (MwRSF), who helped develop the SAFER barrier.

"It is an honour to receive this national award recognizing safety innovations in racing," said Dean Sicking, professor at University of Alabama Department of Mechanical Engineering. "Dr Melvin was a long time mentor of mine starting when I was a graduate student. His leadership and expertise in occupant kinematics and injury causation influenced the next 30 years of careers."

Over the last decade the SAFER Barrier has been a key safety feature for NASCAR and IndyCar circuits, and some European circuits. It is usually found on oval racetracks and high-speed sections of road on street circuits in the US, and is designed to absorb and reduce the kinetic energy during the impact of a high-speed crash.

The project was initially funded by Tony George of the Indy Racing League and the Indianapolis Motor Speedway, and was developed following the deaths of Adam Petty in 2000 and Dale Earnhardt in 2001. That led to a push in safety modifications, and since circuits adopted the barrier in 2005 there have been no fatal wall crashes.

GP3 DRIVER ACHIEVES PODIUM WITH BROKEN COLLARBONE

GP3 driver Alessio Lorandi achieved a podium in the Formula One support series race in Austria, despite racing with a broken collarbone.

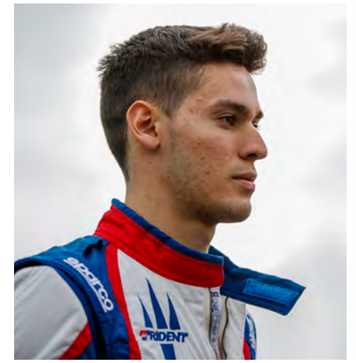
The incident happened a month ago when Lorandi was testing in a go-kart and it flipped over. After being taken to hospital, doctors advised him not to race for the next three months.

"It happened in Germany a month ago," Lorandi said after the race. "I was testing with my kart to stay in shape and I flipped."

Fearing that he could miss races through staying in hospital, Lorandi managed to make a recovery after just 10 days. He now races with a steel plate in his shoulder that helps heal his broken bones, and enables him to make movements in the cockpit while driving.

"It will stay in for a year and a half," explains Lorandi. "When you get in the car, it hurts a lot. But the adrenaline, when you get in that zone, you could have an arm bleeding and you wouldn't even realise. At the end of the race when I got out of the car, I had to wait a bit because of the pain."

"It could have been a win but it's good that we are there after the injury, hopefully we can keep this up," said Lorandi. "I want to try and grab poles and race wins now."



FIA MEDICAL SUMMIT SET FOR ST PETERSBURG

The next FIA Medical Summit and Chief Medical Officers' Seminar will take place in St Petersburg, Russia on 2-3 December.

Professor Gérard Saillant, President of the FIA Medical Commission, will open the summit with a welcome speech on the Sunday. This will be followed by an overview of the latest developments in FIA championships.

In the afternoon, among other presentations, there will be one that draws on the experience from the French Air Force which looks at improving the efficiency of the extrication and medical team by using crew resource management.

On Monday there will be four workshops; one that will focus on extrication for rally cars and single seaters that use the Halo, and another will focus on the safety hazards that come with electrical cars and how it is standardized across different disciplines.

There will be a round table discussion led by Dr Dino Altmann and Matteo Piraccini, based around the prevention of injuries in motor sport.

The summit will be rounded off with a discussion of the day's topics.

INDYCAR INTRODUCES CONCUSSION TEST

IndyCar has introduced a new eye-tracking computer test as a requirement for its concussion evaluation.

The new 'I-Portal Portable Assessment System' (I-PAS) uses a portable virtual reality headset and is able to gauge the ocular motion of the eyeballs and measure the whites, pupils and iris of a driver's eyes, enabling doctors to observe movement of eye muscles.

Developed by Pittsburgh-based eye-tracking experts Neuro Kinetics, I-PAS gives medical professionals a series of 14 tests to determine whether a driver has a concussion, migraines or BPPV (benign paroxysmal positional vertigo).

"That was a game-changer for us," said Dr Terry Trammell, safety consultant to IndyCar. "I-PAS has proven to be an important part of the decision-making process as to if and when a driver may return to competition."

The I-PAS system was first brought to IndyCar's attention back in 2016, when Will Power crashed heavily into the wall during a practice session.

Initially, IndyCar doctors determined that he had a concussion and ruled him out of the race, however further evaluation using I-PAS helped determine that he was in fact suffering from an inner ear infection.

IndyCar has now made the test mandatory for each driver to complete.

FIA LAUNCHES ULTRA-PROTECTIVE HELMET FOR F1

A new ultra-protective helmet standard that will be adopted by Formula One in 2019 was officially launched by the FIA at its Sport Conference in Manila.

The latest standard, called FIA 8860-2018, outlines the construction and testing requirements that the helmet manufacturers must achieve to provide equipment for the FIA's top series. It will be mandatory for Formula One from 2019 and in other championships.

These new helmets will offer a number of safety benefits, including advanced ballistic protection, increased energy absorption and an extended area of protection for drivers.

"Six months after the FIA approved the new standard we have a prototype helmet," said FIA Safety Commission President Peter Wright. "This is the result of a collaboration over a number of years between the FIA, the helmet manufacturers and test laboratories. That is the way safety research and development should happen."

Throughout the research programme, FIA researchers worked closely with F1 helmet manufacturers such as Stilo, Bell Racing and Arai.

Stephane Cohen, Bell Racing Helmets Chairman, said: "The area of testing will be expanded compared to what we currently enjoy, which means that the overall protection of those helmets could be considered better and as usual the FIA will be at the forefront of helmet protection technology."

Dale Earnhardt Jr retired at the end of the 2017 season following a series of concussions

NASCAR MAKES CONCUSSION BASELINE TEST MANDATORY

NASCAR has confirmed that it will be using the King-Devick test, as part of its process to diagnose a concussion in a driver after an accident.

Developed in association with Mayo Clinic, the King-Devick (K-D) test measures a person's eye movement, while they are asked to read out numbers from left to right as quickly as possible without making any errors.

The times required to complete each card are recorded and it captures impairment of eye movements, attention, and language, to determine if a person has a concussion.

NASCAR's introduction of the K-D test follows the retirement of Dale Earnhardt Jr, who put his exit from the series down to the number of concussions he received while racing, including one that caused him to miss the second half of the 2016 season.

"The field of concussions is constantly evolving, and we work with experts across the country in maintaining a proactive approach to prevention and assessment," said a NASCAR statement. "At those experts' recommendation, we are implementing the K-D test as part of a basic neurological exam for drivers in the IFCC."

All drivers were required to complete a baseline test by 8th July, for the tool to be used in infield care centres on race weekends.

NASCAR joins the ranks of other professional worldwide sporting organisations that utilise the K-D test, including NHL and Rugby Football Union.

AUTO+MEDICAL GLOBAL NEWS

NEW FIA MEDICAL COMMISSION MEMBERS

Two new members have joined the FIA's Medical Comission, Dr Jacques Bouchard from Canada and Dr Brigitte Pasquier from Monaco.

Dr Bouchard has been involved in the Canadian Grand Prix since the race began in 1978, as the Director of the Track Medical Centre and then Chief Medical Officer. He has been a key figure in advancing the field of the delivery of health care at motor sport events in Canada and around the world.

Dr Pasquier joins the Medical Commission having been part of the Medical Commission and a senior member of the Automobile Club de Monaco.

Dr Bouchard and Dr Pasquier have replaced Professor Hugh Scully and Dr Robert Scarlot respectively, both of whom have retired from the Medical Commission, but will remain active in Motor Sport.

This has been part of a new age limit of 75 that has been placed on all members of FIA commissions from this year onwards.

Dr Scarlot was a key player in developing the extrication process and is also one of the Vice Presidents for the Automobile Club De Monaco.

Professor Scully has worked in motor sport medicine since 1968, having previously worked as Medical Director for the Canadian Grand Prix at Mosport and subsequently Montreal.

PIRELLI F1 BOSS REVEALS ROLE AS AMBULANCE DRIVER

Pirelli Formula One boss Mario Isola has revealed that he works night shifts as an ambulance driver.

Having started out as a test driver for Pirelli's road car division, Isola uses this experience to help his local town as a volunteer for their ambulance service on non-race weekends.

"People with a normal day job are obliged to volunteer and drive one night shift a week," he explained to F1 Racing. "At weekends, 90% of the ambulance service is made up of volunteers. We start at 7pm and finish at 5am. There's enough time afterwards to go home, take a shower and go to work."

His role in the local ambulance service extends to designing the course that trains ambulance drivers in the Lombardy region of Italy. This is now used by 100 instructors, and has seen over 5,000 drivers come through the programme.

SAFARI RALLY UTILISES WRC MEDICAL EQUIPMENT

A round of the African Rally Championship utilised World Rally Championship medical equipment earlier this year.

The Safari Rally Project was given cutting edge medical tools, to be used in emergencies during the 2018 ARC Safari Rally. Local stewards operated the safety equipment, and were trained by FIA-appointed experts from South Africa.

Supplies included the Thomas Advanced Trauma Support Kit, which is considered to be the standard in life-saving situations around the world. They also had access to an advanced hydraulic extrication device, which can cut through metal and peel off glass.

Having this equipment enabled the Safari Rally Project to put on a WRC-style event, which is key to a planned return to world championship status after losing it in 2002.

With a 1.8m boost in funding from the Kenyan Government, the Safari Rally Project could utilise the equipment delivered by Medisurge, a Malawi-based company involved in the distribution of medical tools.

Dr Alex Gikandi, a director of Medisurge, said that it could handle any sort of emergency put in front of it and was even used during a visit by former US President Barrack Obama.

"We are not taking anything to chances," said Chief Safety Officer Nazir Yakub, who thanked Medisurge for donating first aid kits for every car in the Safari for free.

AUTO+ MEDICAL VIEW FROM THE GROUND

VIEW FROM THE GROUND:

DR JOSÉ CUARTERO

In the first of a new column from the frontlines of grass roots motor sport, Dr José Cuartero gives his views from the ground in Spain.

I have been involved in motor sport for more than 45 years. First as a racing driver, and then as medical chief of the Federación Aragonesa de Automovilismo (FADA), and then as President of the Medical Commission at the Real Federación Española de Automovilismo (RFEdA). I have worked as Medical Chief or Rescue Doctor, in all types of motor sport both cars and motorbikes.

In Spain there are five karting circuits with FIA homologation: Zuera, Motorland, Fernando Alonso, Lucas Guerrero and Campillos. The Spanish Championship (RFEdA) is celebrated in them, in the different categories (alevin, cadete, junior, senior and senior KZ2).

In the case of Karting, the conditions are not always ideal, as the events are organised by clubs and promoters with fewer resources that may lead to cost cutting in safety matters. Another problem is the hiring of medical personnel with adequate training. In our sport, it is essential that both doctors and paramedics have adequate training in the initial care of the injured driver.

The most frequent injuries in Karting are cervical whiplash and fractures of the fingers, wrist (ulna and radius), ankle (tibial malleolus and peroneus) and ribs. There are frequently dermal lesions and microfractures of ribs at the level of the edge of the seat.

There have been many improvements in Karting safety in recent years. At the RFEdA level, the rules of Medical Services for Karting have been published (Annex 1 of Medical Services for Testing), and some intervention protocols have been drawn up (Circuito Internacional de Zuera). But the lack of evolution in safety matters for the driver is worrying. More studies and new designs are needed to protect the body of the driver especially in case of rollover.

It is necessary to require from the Circuits the application of a Safety Regulation that must be agreed on a National level, following the standards already established by other Federations. This Regulation must contemplate the requirement that the medical and paramedical personnel be properly trained for the initial care of the injured/ traumatized driver.

In general, it is not difficult to recruit volunteer doctors. What is difficult is finding doctors with the right training for the needs of our sport. That means experts in the initial attention to the injured. When there is a traumatized driver, the important thing is the initial care that includes cardiopulmonary resuscitation, adequate immobilization, stabilization and transfer to an appropriate Center, and this cannot be done by any doctor.

It would be interesting to promote at University level a specific training in the initial care of trauma in our sport. Currently it is not usual in Schools of Medicine and other University Schools, but the few initiatives that are made in this regard get much interest among students.

In grass roots motor sport you learn to work as a team, especially as resources can be limited. The doctor must know the Regulations, the Safety Plan of the championship and the available means at his fingertips. He must be aware of his responsibility and, therefore, he must be involved together with the Organizer in the hiring of the medical means, and in the alert communication with the Emergency Services in the area and the knowledge of the appropriate hospitals for transfers. It is also important to know the functions of the other race meeting Officials, especially those of the Race Director and Track Marshals.
This is essential for the coordination of the interventions (team work)."

Dr Cuartero has worked with both cars and motorbikes

AUTO+MEDICAL FEATURES

FEATURES

SEATING PAINS

AUTO+ Medical examines the latest medical advice around seat design and how new technologies are being used to help prevent driver injury.

AUTO+MEDICAL FEATURES

While this year's Spanish Grand Prix might have been a straightforward lights-to-flag victory for Lewis Hamilton, Williams driver Sergey Sirotkin described it as "the toughest race" of his life.

After threading his way through the wreckage of Romain Grosjean's opening-lap crash, he started to feel discomfort from his seat. "I was really struggling with seat comfort and just staying in the car," he said after the race. "It was a very painful feeling I was getting."

Sirotkin was in fact struggling with posture-related problems in the cockpit of his Williams, particularly with the angle of the shoulder pads that go towards his HANS device. Rather than holding him in place, they were pushing him down into the seat, which caused significant discomfort through the corners.

"Seating position is one of the most underestimated performance and safety items," says Grand Prix Drivers Association chairman Alex Wurz. "Sometimes even in a small accident, a bad seat can actually cause a lot of damage in relation to the crash or off itself."

It is not an uncommon problem. Over the years, a number of drivers have suffered due to seat-related issues and often the correct posture within a seat can be the difference between getting injured in an accident and escaping unscathed.

Finnish driver Valtteri Bottas had a similar issue in 2015 when he missed the Australian Grand Prix because of a back injury he sustained during qualifying. He traced the problem back to his seat position in the Williams car, with the bumpy nature of the track in Melbourne compounding the injury.

"It was the seat and pedal position," he said at the time. The team made changes to put his back in a more neutral position, which put less pressure on his discs and this solved the issue. However, Bottas admits he was surprised to have the problem in Australia, with no signs that his seat position wasn't right."I've never had any problems before with the lower back. That kind of thing normally takes a bit of time to build up. But there was no warning, it just went suddenly."

Wurz has helped the FIA and Toyota with research

"SOMETIMES EVEN IN A SMALL ACCIDENT, A BAD SEAT CAN ACTUALLY CAUSE A LOT OF DAMAGE IN RELATION TO THE CRASH OR OFF ITSELF"

This is not just an issue in F1 but across motor racing – single seaters, sports cars and rallying.

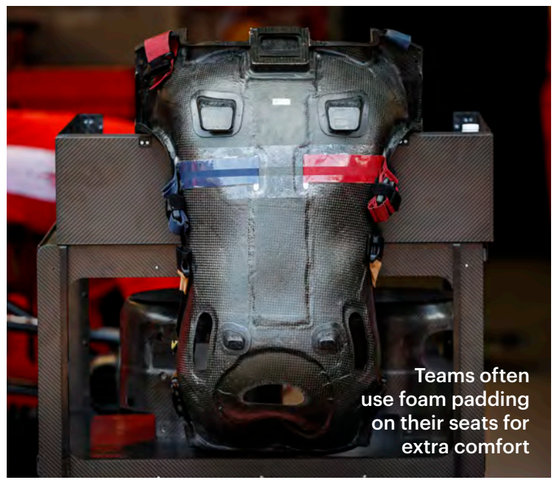
CONTROLLING FORCE

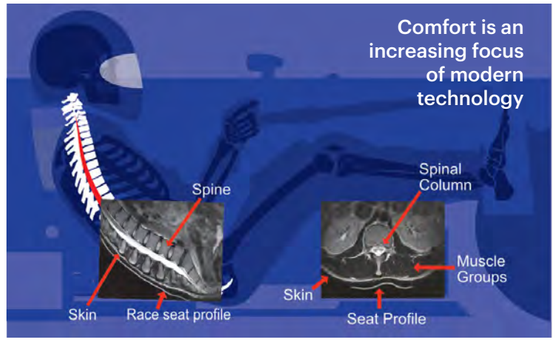
When making a race seat, a team's main goal is to replicate the driver's body shape in the car but it is difficult to replicate the G-Forces a driver will face. So it can be a challenge to ensure that the seat works in conjunction with the other safety systems on the car.

"When you just sit in an empty monocoque your body is not protected left and right, and that means your spine is not in the correct shape," says Wurz. "So I can only recommend to all the young professional drivers out there to be extremely accurate, and go into great detail when you are making your seat. Make sure it's your seat and not just some foam insert, and that it's a really good seating position in relation to the seat belts, the HANS device, safety points like the headrest and so on."

This is especially important for lower-level single seater racing where there may not be a budget for a specially-moulded seat for the driver.

"I see drivers sitting in a Formula 3 or Formula 4 car with just foam all around them and they aren't sitting in the proper seat," adds Wurz. "You will hardly be able to feel what the car does and if you have an impact, all of the safety devices which are designed around the seat will then work with much less efficiency."


Teams often use foam padding on their seats for extra comfort



REPLICATING THE COCKPIT

To help prevent these issues some teams are consulting experts to ensure that the seating position of a driver does not create unnecessary strain on his body.

UK-based consultancy F1 Spinal Solutions, which works with the Mercedes F1 team, uses a special upright MRI scanner to scan a driver's spine and muscles whilst sitting in the race position. This offers greater insight rather than using a conventional tunnel-type MRI scan, and gives them the opportunity to advise drivers and teams on how to mitigate for potential issues.

"The MRI machine is clever enough that it can pick up the driver, the skin, the muscles, and the shape of the spine," says radiologist Dr Steven Morgan, one of the founders of the company. "The upright scanner is essentially weight bearing and we can load a driver sitting, bending forwards and backwards, which allows us to tell if the (spinal) disc is stable and physiological as opposed to normal loading where they are lying down."

Since launching the company two years ago, Morgan has worked with a number of F1 drivers, including one who was suffering from pain during rapid decelerations. By analyzing an MRI scan with the driver in his normal

racing position, they were able to identify the cause of the problem.

They found that when the muscle groups were working hard, the blood flow increased dramatically, resulting in muscle engorgement. In a tight-fitting seat, there was no space to accommodate this swelling, which therefore resulted in pain. So the seat design, which seemed to fit the driver perfectly when the car was stationary, had to be changed to allow for muscle changes in a racing environment.

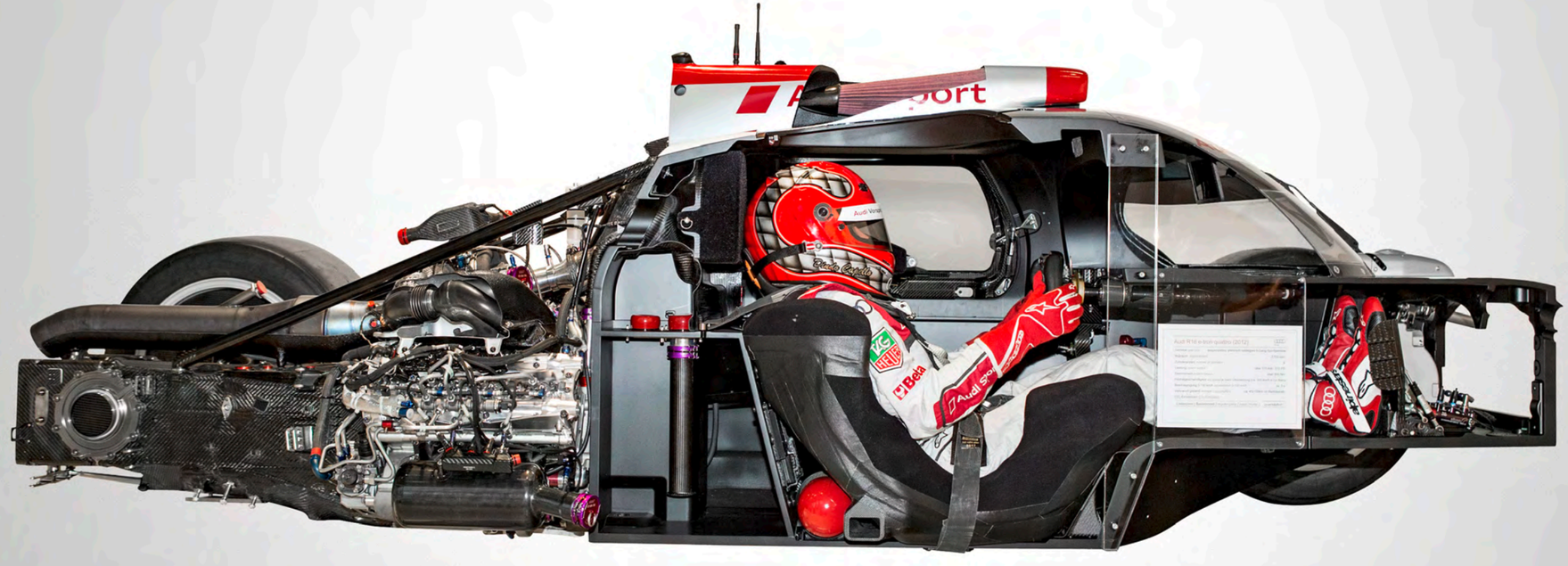
Quite often teams will put padding in the driver's cockpit, which is designed to help with any discomfort and stop the driver 'submarining' under braking. But these can be misplaced or not the right type of material, meaning it could be subjected to increased degradation over time due to the high temperature and G-Forces that drivers are subjected to.

"You can easily tell by looking at the seat that the padding is in the wrong place," says Morgan. "With the drivers' recurrent (G-Force) loading they often put a foam insert down the center of the seat to give them a little bit of padding. That's often not in the correct place, or offline. There are different kinds of cushions for different kinds of spines, and we try to glean most of what their problems are and how to fix them."

Morgan explains how they were able to see this information after conducting a series of experiments when drivers still complained they found back pain returned, even when they were happy with the inserts. "From this we could infer that there was significant foam degradation within the hostile driving environment," says Morgan. "We advised the teams to fit new inserts every 2-3 races, solving the issue."

AUTO+MEDICAL FEATURES

"WITH THE RECURRENT G-FORCE DRIVERS USE A FOAM INSERT TO GIVE THEM MORE PADDING. THAT'S OFTEN NOT IN THE CORRECT PLACE."



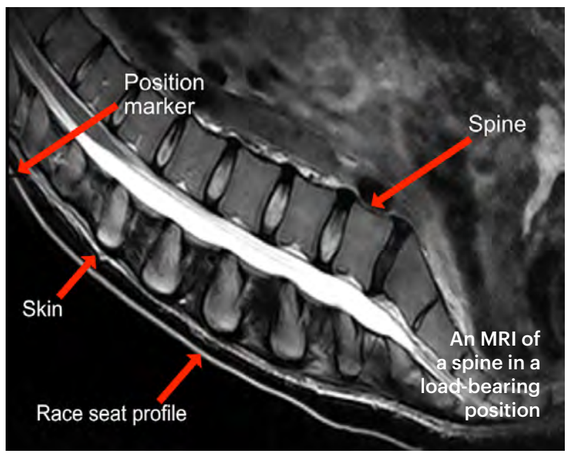
Regulations on seating position are set to change for LMP1 in 2020/21

Even minimal compression of foam inserts can make a huge difference to the driver. “We can go down to a millimeter if we need to and see how different foams compress under weight bearing,” adds Morgan. “If you have a two-centimeter foam insert for the driver and tell them it compresses to 50 per cent, that’s quite important even in the virgin state of the foam because it will incur quite a lot of degradation over a few races.”

SCOPE FOR EVOLUTION

Whereas drivers in F1 have the luxury of making seats to suit their body shape, in sportscar racing it is a different affair. They often have to share the car with two other drivers, with the seat itself changing every time they do a driver change.

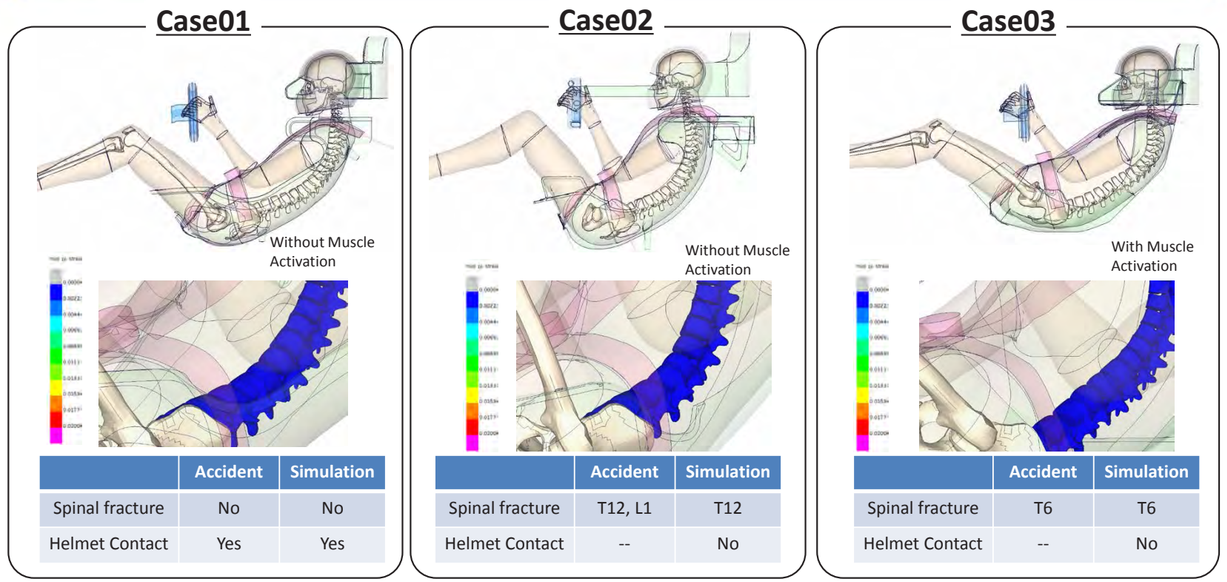
“In my case, because I’m the tallest I have the carbon seat, which is shaped to me and then the smaller team mates will have the foam inserts,” says Wurz. “It’s the same story for the foam inserts, but also for the safety of the positioning of the steering, that has to be the best compromise possible where always the number one priority is safety, two is performance and three is comfort.”



Following Anthony Davidson’s heavy crash during the 2012 running of Le Mans, when he crushed two vertebrae in his lower back after his LMP1 car was launched into the air, the FIA conducted an investigation into how he was injured.

While it was not clear whether it was the vertical landing or frontal impact with the barriers that caused the injury, it was a concern for the FIA, which was already investigating Guillaume Moreau’s head-on crash in an LMP2 car at the Le Mans Test Day, when he also sustained an injured vertebra.

As such, the FIA teamed up with Toyota Motor Company to use its Total Human Model For Safety (THUMS) software, which is a computer model that represents the human body. This enabled them to recreate body parts using their Finite Element modelling and simulate how individual bones and organs react in the event of an accident.



	Accident	Simulation
Spinal fracture	No	No
Helmet Contact	Yes	Yes

	Accident	Simulation
Spinal fracture	T12, L1	T12
Helmet Contact	--	No

	Accident	Simulation
Spinal fracture	T6	T6
Helmet Contact	--	No

Reconstructions of Lopez (Case 2) and De Jong's (Case 03) crash injuries

From there, they were able to recreate Davidson’s crash and compare it to Wurz in the same scenario for a smaller and taller driver. They found that the smaller driver (Davidson) ended up moving around in the cockpit more during an impact, whereas for the taller driver (Wurz) there is less distance for them to travel because they are rested against the monocoque.

This technology has been used to analyze other impacts such as Toyota driver Jose Maria Lopez’s accident during the 2017 Silverstone race where he sustained “minor damage” to two vertebrae, and Daniel De Jong’s crash at Spa Francorchamps in which he fractured the T6 vertebra during a GP2 race after colliding with Pierre Gasly and slamming into the barrier, head-on at high speed.

“IT HAS TO BE THE BEST COMPROMISE POSSIBLE WHERE THE NUMBER ONE PRIORITY IS SAFETY, TWO IS PERFORMANCE AND THREE IS COMFORT”

“This is actually resulting in a rule change, because we had a few accidents where we had broken spines from compression break” explained Wurz, referring to the next LMP1 regulations that will be introduced in 2020/21. “We will have a slightly different seating position to ensure that the pressure between each vertebra is spread out as equal as possible to not have one weak link in your back. This will help to prevent injuries that we’ve seen in the past where either a rearwards or forwards impact compression breaks the vertebrae.”

It is all part of a move to ensure that teams take a safety first (rather than performance first) approach when designing drivers’ seats. The FIA and its safety research partner the Global Institute are one year into a four-year research project using Toyota’s THUMS software to further improve this aspect of motor sport.

The joint project covers research on collisions across motor sport disciplines, and will include analysis of safety elements such as seat structures and seatbelt positioning, with a focus on minimising spinal injury. The results will be used to put forward proposals to update motor sport regulations and safety equipment.

Drivers can rest assured that motor sport safety researchers are not sitting still on this important issue.

DR NAOMI DEAKIN

PhD candidate (Clinical Neurosciences), University of Cambridge

Naomi Deakin is the first doctor to win the Watkins Scholarship, a funded research position with the Global Institute for Motor Sport Safety. She has been involved in motor sport medicine for a number of years, having worked with the Silverstone circuit and the British Touring Car Championship. AUTO+ Medical spoke to Deakin about her ambitions to lead a global study of concussion in motor sport and also use those results to benefit road safety

AUTO+ Medical: You're the first doctor to win the Watkins Scholarship, how does it feel?
Naomi Deakin: Fantastic! When the Watkins Scholarship was first released three years ago I thought it was an incredible opportunity. It was great to see the work that the engineers have completed over the years, and with Sid (Watkins) being a doctor and a neurosurgeon himself I hope I can do him justice by being the first doctor to receive the award.

A+M: Have you always been a follower of motor sport?
ND: From quite an early age yes. My dad was a road mechanic and so I was always

Deakin works with the Silverstone medical team for events like the World Endurance Championship

Deakin conducted a major study with drivers in the British Touring Car Championship

interested in cars, but medicine very quickly became what I was focusing on. I never dreamed that I would be able to bring the two together. It was only through meeting Professor Peter Hutchinson, who is the Chief Medical Officer for Silverstone as well as Professor of Neurosurgery at the University of Cambridge, that I got the opportunity to do some motorsport medical research, which I wasn't really aware of at the time! It's fairly unbelievable that I've been in such a fortunate position really.

A+M: When you started with the motor sport research, what did you think about it?
ND: Well the first thing I found was that in terms of medical motor sport research there isn't that much happening in the UK or even globally, and I think that largely stems from the fact that a lot of the doctors who provide care at motor sport circuits have another day job. So you find that each individual provides medical care in a different way and at very high quality, but that is quite ad-hoc. The first thing I found when I looked at Silverstone was that we needed to start to standardise how we care for the drivers and really create a good evidence base for what we are doing, which was really exciting for me because it means there is almost a blank sheet of paper. We have got a fantastic foundation but also scope to improve on the things we do.

A+M: What have been the results of your research so far?
ND: The first study I did was on injuries in competitive racing. The pilot study had 10,000 patients in it and looked at who was coming to the circuit, how they were injured, and where they were injured on track. We changed some of the marshal posts and where the medical cars were stationed. Later I started a project in my real area of academic interest which is developmental neuroscience and head injury at a very early age. I was working with Prof Hutchinson and we found that there was a real gap in terms of concussion, so actually I moved on then and started working with him for the British Touring Car Championship and things have really moved on from there.

A+M: Will the Watkins Scholarship help with your research?
ND: So what we are doing now is putting together a two-year concussion research programme which will be based in Cambridge. We are in the process of setting up a concussion clinic, which is being attended by some international drivers, but we also have it open to other semi-professional sports participants. But what the Watkins (Scholarship) will do is allow me to create a vital bridge between motor sport medicine and the engineering aspects, because one of the things we really don't understand is what the threshold value is for concussion. There is some excellent work in terms of frontal head protection systems and helmet design which has happened in recent years. But what we have seen in terms of injuries is that we have moved from very severe traumatic brain injuries where drivers have died, and we have sort of shifted drivers on the spectrum towards the mild brain injury which is where we find concussion. As we are moving towards that lower end of the spectrum, we really don't understand what sort of forces, be it their magnitude, or their direction, or the rotation, actually cause the injury. So the fantastic thing that the Watkins Scholarship can do is have some insight into that engineering data and link it up to that medical data that we collect in Cambridge. One of the things we are doing in Cambridge is some very detailed, functional MRI imaging where you see the structure of the brain and you see the connections between different regions that are altered. If we can match that up to the forces that we are able to collect in the car, either in the drivers' ears or on the chassis itself, it will help us to understand how that injury has occurred.

A+M: Could this be a case where motorsport research can really benefit road safety?
ND: Exactly. My ultimate goal would be to correlate motorsport data to the injuries that we see in road traffic accidents. We are in a very privileged position in motor sport as we


Deakin did her pilot study on injuries in motor racing

have our medical teams on site and we also know exactly what has happened in the accident; we have the video footage and all of this other engineering data. If we can use what we learn in that environment to translate it to road safety, I think it has some really outstanding possibilities for improving care for patients after road traffic accidents.

> **“ MY ULTIMATE GOAL IS TO MARRY THE DATA WE GATHER, TO INJURIES WE SEE IN ROAD TRAFFIC ACCIDENTS ”**

A+M: Previous Watkins Scholars have been based at the Global Institute's office in Geneva, is that something you are going to do?

ND: Actually it will be fairly different from how the Watkins has worked previously. With the way medical licensing works I am a doctor in the UK but as soon as you leave that isn't transferrable unless you get a licence from a different country. That is why we have the permanent medical delegates for the FIA championships and the local doctors too because they have the medical certificate valid in each country. For the 2018 Sid Watkins Scholarship, I will be based here in Cambridge to enable me to complete the concussion research project and to support the sports concussion clinic with Prof Hutchinson, but then I will travel to the Global Institute or the Research Working Group meetings and the Scientific Advisory Committee meetings in Paris, and also whenever I need to spend some time to learn some new skills, with the Accident Data Recorders (ADR) for example, so it is sort of shared between the two locations.

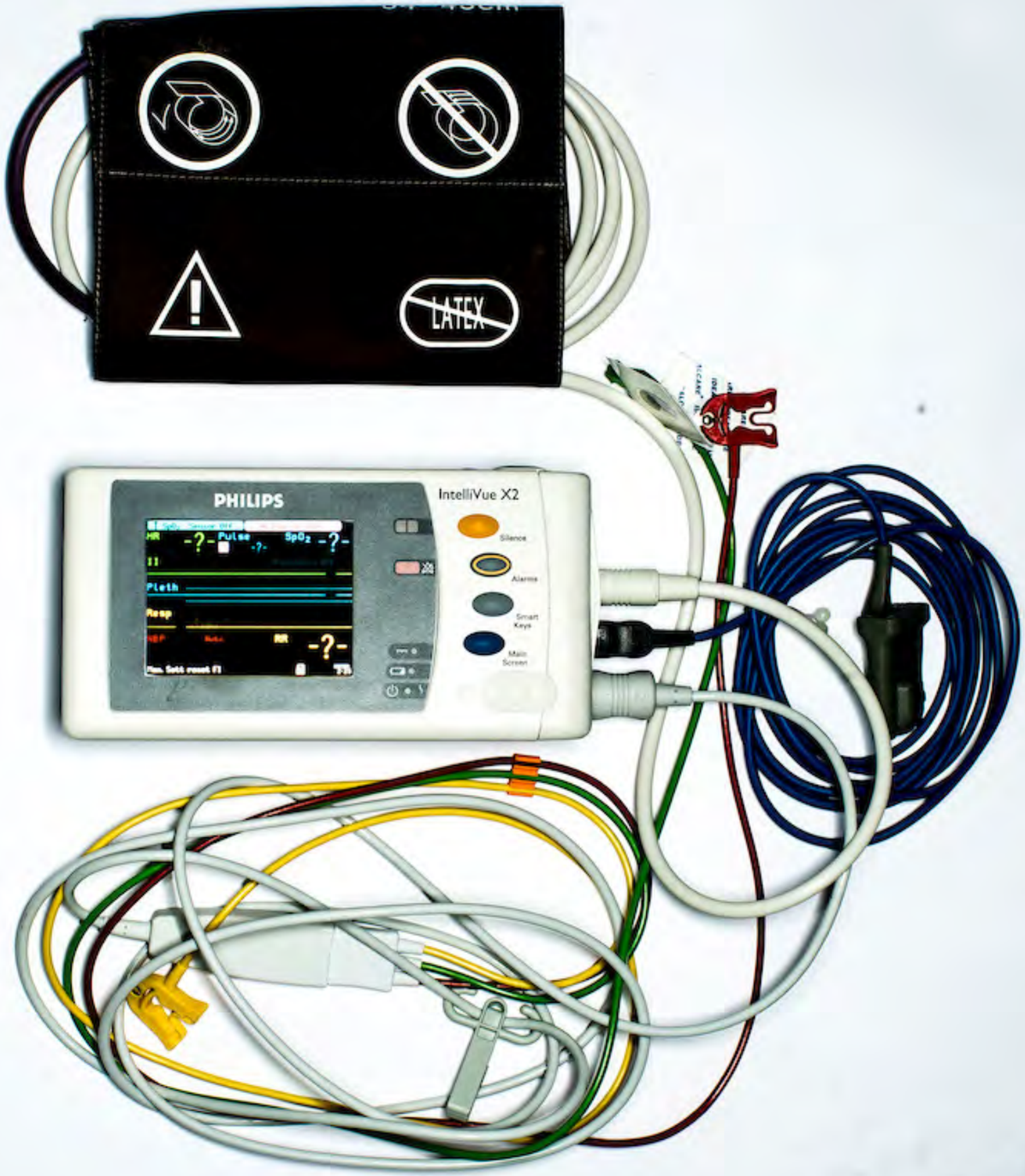
A+M: Will you continue with your other work on motor sport?

ND: I'll continue the relationship I have with touring cars (TOCA), where nominally I am their concussion expert, so I do all of their baseline and post-injury concussion testing for touring cars, Formula 4, and the Porsche Carrera Cup - all of the series that are associated with TOCA. I'll continue to travel around the UK with them, but hopefully in light of the Watkins Scholarship I will have more of a role reviewing the accident and the ADR data from Formula 4 for example, and also providing a point of contact.

A+M: What are your ambitions in motor sport medicine?

ND: They're evolving all the time! In general, motor sport medicine is creating its own area of expertise; my personal experience is that we are a very small community that is producing some fantastic pockets of work around the world. There are a few conferences and seminars happening that make sharing that knowledge easier and there is a growing social media movement which facilitates the sharing of our professional knowledge on Twitter. Specifically there are a couple of groups in the US and in Canada and Australia, so I can see motor sport medicine really evolving as an international entity over the next few years and the Watkins Scholarship will hugely help that I think.

Deakin will continue to work at the race track throughout her research



AUTO+MEDICAL FEATURES

INSIGHT: MEDICAL MONITORS IN MOTOR SPORT

Medical monitors are essential for assessing driver injury after an accident. **Dr Paul Trafford** analyses the best options for the motor sport environment.

Additional research: **Dr Robert Seal** and **Dr Matthew Mac Partlin**

Motor Sport medicine pre-hospital emergency care has its own unique demands and challenges, requiring special expertise and equipment. One of the most important requirements is the ability to monitor the physiological parameters of any injured, or potentially injured competitor, both in their vehicle during rescue and extrication, and during transfer by whatever means to a definitive medical facility.

In recent years there have been significant advances in technology, battery life and the parameters that can be monitored, along with better packaging to make the monitors more user friendly, reliable and smaller.

There are also minimum standards for monitoring laid down by various medical bodies, such as the Royal College of Anaesthetists in the UK, but whatever your specialty, there is a standard of care that should be provided in motor sport and applied to everyone at the track.

The FIA Appendix H mentions the use of a heart monitor, a defibrillator and a device for measuring oxygen saturation, leaving the choice of how this is achieved to the individual; yet the choice of what to use and how to comply with not only the FIA regulations but also the requirements of what any physician would deem necessary, is both complex and varies around the world.

With this in mind, AUTO+ Medical has explored what is available, who is using what, and what an ideal monitor might have.

It may be that you use different items of equipment to monitor each parameter, so a Non-Invasive Blood Pressure machine, a separate ECG, perhaps integrated with an AED and a separate pulse oximeter, but it is much easier and practical to have everything in one portable monitor and that's what is being considered here.

So, what monitoring parameters would an ideal medical monitor in motor sport have?
The minimal level of basic monitoring available for a driver who may be trapped in a car or injured or ventilated should include:

- ECG with pulse rate - three leads, ideally with the option of five or 12 leads
- Pulse Oximetry SaO2
- End Tidal CO2 waveform display
- Non-Invasive Blood Pressure
- Defibrillation using external paddles or pads

Alongside this there are other parameters that may be desirable:

- 12 lead ECG
- Temperature monitoring
- Carbon Monoxide monitoring using Masimo's rainbow sensors
- ST analysis of the ECG
- Arrhythmia monitoring
- The ability to externally pace using the defibrillator pads
- Invasive Pressure monitoring

It's not unusual to find many of these physiological parameters available in one monitor and several devices are available, with the top three providers probably being:

"IN RECENT YEARS THERE HAVE BEEN ADVANCES IN TECHNOLOGY, BATTERY LIFE, AND THE PARAMETERS THAT CAN BE MONITORED"

ZOLL, which produces the Zoll series X with monitor and defibrillator in one unit.

PHYSIO CONTROL Lifepack SERIES 15 with monitor and defibrillator in one unit.

Remote Diagnostic Technologies RDT, a small company that has just been bought by Philips. It has one of the smallest monitors on the market, the Tempus Pro designed and built for military use, which links by Bluetooth with a separate small stand-alone defibrillator which can be used by itself or in conjunction with the monitor as the Tempus ALS.

So, besides the actual monitoring what else is important?

SIZE AND WEIGHT

The actual size and weight of the monitor are extremely important. The monitor must be small enough to fit into a closed car if there is an injured driver who is trapped. Using long cables having them trailing outside and trying to position the screen so it can be seen by the rescue and medical workers inside the car are both difficult and can lead to cables being tangled and the monitor being unable to be seen. It's not unusual for someone to have to hold the monitor for long periods so it can be seen so we don't want something so heavy it becomes unmanageable. A small footprint is useful allowing the monitor to be positioned in smaller places.

BATTERY

Any monitor has to be able to run on batteries as mains power is not an option. A long battery life with rapid charge facility and the ability to replace the battery without losing monitoring or data is vital. It's also important to know if the battery can be charged in the monitor or has to be removed and charged in a separate unit.

ENVIRONMENTAL CHALLENGES

Motor Sport and pre-hospital care are harsh environments with often exacting conditions involving heat, snow and ice, rain and dust. Any monitor must be able to withstand these extremes and continue working at a range of temperatures, not lose the battery charge or allow water and dust to enter. At some point, any monitor will be dropped so it has to be able to stand some hard use. Many motor sport events rely on the loan of equipment and medical providers from various backgrounds, so it is unlikely everyone will be familiar with the same equipment. Some degree of training and familiarity is very important along with a device that is intuitive and user friendly with easy to use menus and rapid starting and set up.

SCREEN

A large colour screen is essential, which can be seen in bright sunlight and from an angle as well as straight on.

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Some monitors are able to incorporate voice recording with still and video cameras

ALARMS

These are important and must be audible as well as visual as it may not be easy to hear alarms if an event is continuing and you are trackside. They should however be easy to silence and the thresholds simple to adjust.

MEDIA

Some monitors now incorporate voice recording as well as still and video camera that can store this media alongside the physiological data; this can provide a very useful record for any receiving hospital and prove invaluable for reviewing the care that was provided.

COST

All the monitors are expensive sophisticated devices and can cost up to €25,000 with all the options. The companies often help with purchase or may help with loan equipment for big meetings such as F1.

ADDITIONAL FUNCTIONS

The RDT Tempus monitor has the ability to incorporate a video laryngoscope and ultrasound probe, but these are of course available as stand-alone devices

So who uses what?

In the USA at the Circuit of the Americas, on track Zoll X series is used, and at the medical centre Lifepack 15. In Australia Zoll M series and Lifepack 20 with options ETCO2 and the Tempus Pro are used. In Singapore the Zoll X series is used in the medical centre and for transfer, and Lifepack 15 or Zoll X in the medical cars. In Germany the Lifepack 15 is used, and in the UK Philips provide the monitoring. In the UK, Zoll, Lifepack and Tempus are used, with Tempus increasingly being used by various Ambulance services.

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MONITOR / DEFIBS	Physio-Control Inc.	ZOLL Medical Corporation	Remote Diagnostic Technologies Ltd.	GS Elektromed. Geräte G. Stemple GmbH	Philips Medical Inc.	Schiller AG
Product	**Likepak 15**	**X Series**	**Tempus ALS**	**Corpuls³**	**HeartStart MRx**	**Defigard Touch7**
GENERAL						
Fully featured monitor-defib; Manual / AED / Cardioversion / Pacing	Yes	Yes	Yes with built in cameracamera and optional ultrasound and fibre-optic laryngoscope	Yes	Yes	No - no pacing
Weight fully configured with battery, without accessories or saddle bags	9.1 kg	5.3 kg	5 kg (2 modules)	6.3 kg (3 modules)	6 kg	3.2kg (2.4 kg monitor plus 0.6 kg printer)
ENVIRONMENT						
Ingress Protection - total product	IP44	IP55	IP66	IPX4	IP24	IP55
BATTERY						
Rechargeable batteries	2 batteries - Lithium-ion	1 battery - Lithium-Ion	2 batteries - Lithium-Ion	3 batteries - Lithium-Ion	2 batteries - Lithium-ion	1 battery - Lithium-Ion
Capacity - A/h	5.7 Amp hours	6.6 Amp hours	10.2 Amp hours / 5.8 Amp hours	4,4 Amp hours		5.8 Amp hours
Capacity - Nb of shocks	420 shocks at 360J	300 at 200J	300 at 200J	200 at 200J	Every 15/min 20 200J discharges	
Capacity - Monitoring only	6 hours	6 hours	10-14 hours (monitor) / 10 hours (defib in monitor mode)	4 hours	9 hours	
Charge Time of an empty battery	4.25 hours	4 hours	4 hours (monitor) / 2 hours (defib)	2 hours	3 hours	
DISPLAY						
Size	8.4 inches (21.6 cm) diagonal	6.5 in (16.56 cm) diagonal	“6.5 in (16.56 cm) diagonal - monitor	8.4 inches (21.6 cm) diagonal	8.4″ diagonal (128 mm x 171 mm)	7 inches (17.8 cm) diagonal
5.7 inch (16.5 cm) diagonal - defib”	8.4 inches (21.6 cm) diagonal	8.4″ diagonal (128 mm x 171 mm)	7 inches (17.8 cm) diagonal			
DEFIBRILLATION						
Charge time on Battery at 200J	<10 seconds	7 seconds	8 seconds	<10 seconds	5 seconds	
Time to first shock at full power from switch-on	15 seconds	20 seconds	13.8 seconds			
MONITORING OPTIONS						
12 Lead ECG Monitoring and re-cording	Yes	Yes	Yes	Yes	Yes	Yes
Co-oximetry e.g. SpMet, SpCO, SpHb	Yes	Yes	Yes	Yes	No	No, SpMet & SpCO only
NIBP	Yes	Yes	Yes	Yes	Yes	Yes
Temperature	Either IBP or temp Not both together	Yes - 2 channels	Yes - 2 channels	Yes - 2 channels	Yes - 2 channels	Yes - 1 channel only
Pacemaker	Yes	Yes	Yes	Yes	Yes	No
Patient record feature	No	No	Yes	No	No	No

ADDITIONAL FEATURES: ST monitoring is provided by Lifepack and Tempus with QT monitoring on the Tempus and Phillips. Impedance respiration is only on Zoll and Tempus. All include invasive pressure monitoring to varying degrees but the Lifepack can only monitor temperature or invasive pressure, not both together. All have built in Bluetooth Zoll and Tempus having USB and WiFi connectivity. Only Tempus provides built in 4G mobile connectivity, although Corpuls has 3G available. Both Tempus and Corpuls can provide real time data streaming allowing remote monitoring, however Tempus also allows remote voice communication. The tempus is also cyber secure as it was developed for military use.

NOTE: The author uses a variety of monitors in his clinical practice and BTCC has purchased a number of Tempus monitors. A+M has no relationship with any of the manufacturers in this article.

AUTO+MEDICAL FEATURES

INSIDE THE 2018 F1 SAFETY CAR

AUTO+ Medical takes a look at the new Formula One Safety Car, the most powerful ever produced.

As Formula One gets faster safety has to keep up. This is why Mercedes have this year launched the most powerful F1 Safety Car ever, with 585bhp and a top speed of 318km/h.

This power is important as the safety car must maintain a minimum speed level to prevent the tyres, brakes and engine of an F1 car from excessive cooling and overheating. That is why the all-new 2018 AMG GT R features the driving components carried over from its AMG GT3 racing car that was developed on the famous Nurburgring circuit.

It is the 23rd consecutive year that Mercedes has provided such a crucial element to F1 weekends, and this year it is again driven by Bernd Maylander alongside co-driver Richard Darker who maintains radio contact with race control.

It has a fully redesigned suspension, active aerodynamics, extra supports to boost torsional rigidity, nine-position traction control, adjustable coil over spring/damper units, and will drive F1 tracks around the world on Michelin Pilot Sport Cup 2s.

Inside the cockpit there are two integrated iPads; the left is used to display the international TV broadcast and the right can feature either an animated display of the current positions of cars or show current lap times. On the dashboard there are the marshalling system LEDs (flag signals), control LEDs for the Light Bar and Flashing Lights, and switches for the Light Bar, Flashing Lights and Siren. There is also a secondary rear-view mirror for the co-driver, and radio system buttons for both on the centre console.

In the boot there is enough space for the telemetry units, a Wi-Fi router which links to the iPads, onboard camera and timing system unit, siren control unit, marshalling system unit, FIA SDR (software defined radio) unit, car data logger, and the Safety Car Systems fuse and relays box.

All of this equipment ensures that it is not just the fastest safety car ever produced, but the safest one too.

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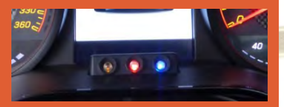
Switches for Light Bar, Flash Lights and Siren

Control LEDs for Light Bar and Flash Lights

Marshalling System LEDs (Flag Signals)



Co-Driver Rear View Monitor

Onboard Interior Camera Second one behind Driver Seat

Radio System Control Buttons

iPad
TV Feed
Timing Page
Positioning Map
Information Page

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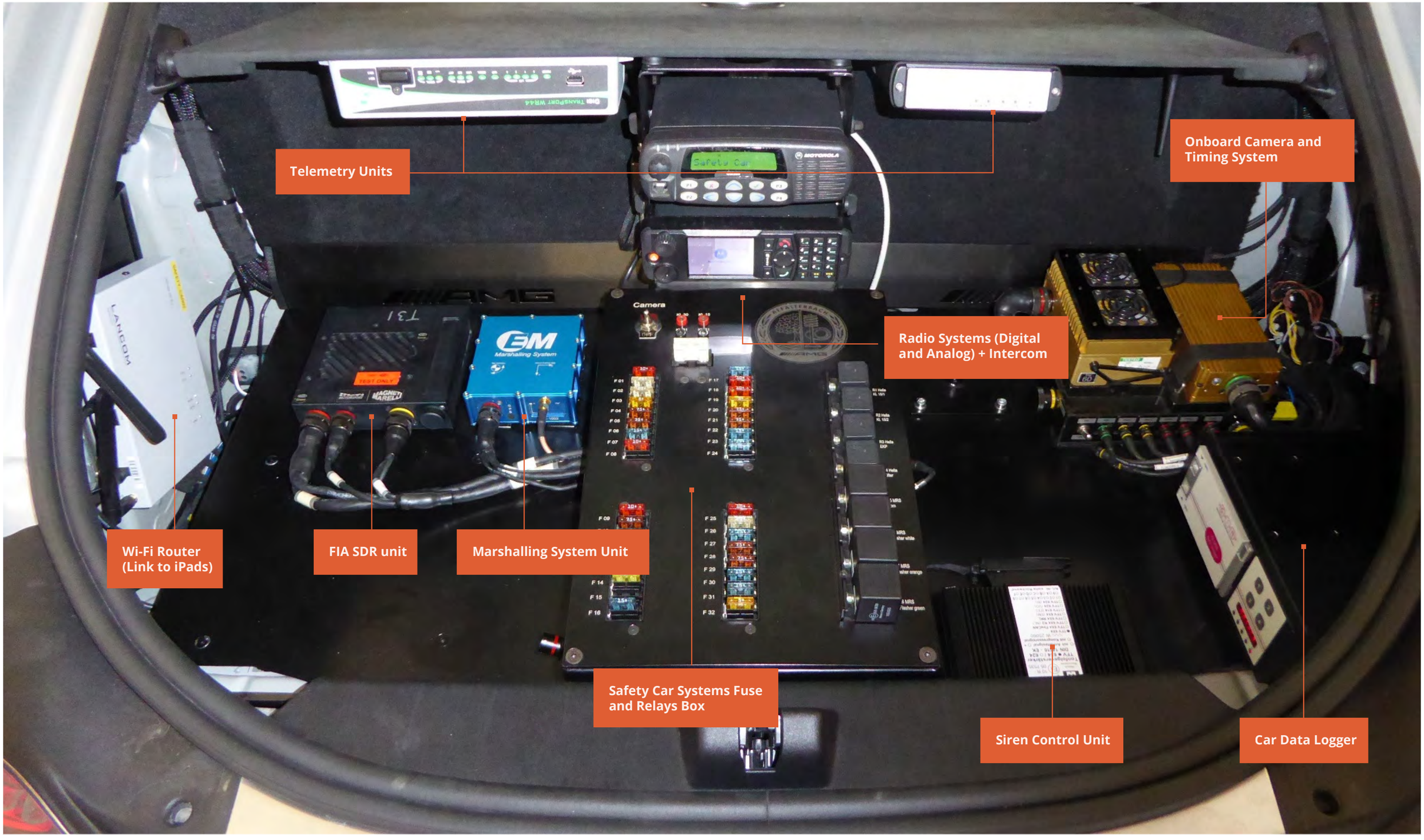

Monteiro spun off at 255kph while testing with Honda at Barcelona

THE ROAD BACK:

TIAGO MONTEIRO

The World Touring Car Cup driver reveals his remarkable road to recovery following serious injuries sustained in a heavy crash in September 2017.

During the closing stages of a three-day test at the Circuit de Catalunya last year, Tiago Monteiro lost control of his World Touring Car after the brakes failed at 255kph. Heading into the first corner, the car spun and went backwards into the wall. The impact resulted in him sustaining two head traumas, a dislocated shoulder, and a brief loss of vision in his eyes. But after spending months recovering and consulting doctors around the world, Monteiro tested with Honda again this year with plans to return to racing in 2019. He spoke to AUTO+ Medical about his injuries and on-going recovery.

AUTO+ Medical: What can you tell us about the accident itself?

Tiago Monteiro: I had a mechanical failure with the brakes and went off the road at 255kph. I tried to avoid hitting the wall head on at Barcelona into the first corner. This is a very high-speed place with not a lot of run

off, and I tried to avoid that and go to corner number two. But at that speed obviously you don't have a lot of control, so I turned and went onto the grass and spun. Then I hit the wall, slower but still at 170kph and 44G acceleration, which knocked me unconscious.

A+M: How long were you unconscious for? Obviously you weren't awake for this point, but do you know what happened in terms of the extraction from the track?
TM: It was towards the end of the day, all of the stewards were getting ready to go so they were quite fast. But because I wasn't breathing properly and was unconscious they were a little bit worried to touch me and extract me, and my pulse was very low. In the meantime my team manager and mechanics arrived and were also quite worried. Then the medical staff arrived, but it was not easy to get me out of the car. I was put into a hammock, then into a medical helicopter, so from the time it took to get me out of the car until I got to the hospital, it was probably like 15 or 18 minutes max. I did a lot of (medical) exams and observations, and then I woke up in the bed with a huge headache. I couldn't talk, move my right side, feel my right leg, I had no speech, couldn't swallow liquids, I couldn't see because I had 85 per-cent strabismus.


Monteiro had to wear a patch over his eye to prevent feelings of dizzyness

Honda gave Monteiro a test at Monza last month

A+M: What caused that?
TM: The extension of the Cranial Sixth R, which is the nerve that puts your eyes to the side. So it was like as if my eyes came out of my sockets and it extended the nerve, and then in the lateral impact I scratched and squeezed C1 and C2 cervical, which then squeezed the canal where the nerve goes into your spine. So not only was it squeezed, but it was also stretched. A lot of times you don't recover from it, but thank god sometimes you do recover from it. I also dislocated my shoulder, which tore a lot of tendons and muscles around there. My back was scratched, I tore my biceps, bruised four ribs, and my toes and knees were completely in blood because I destroyed the pedals and everything inside the car with the lateral impact. There was a lot of injuries, but the most concerning was my neck and two traumas in the head, that's why I was under observation in intensive care.

A+M: Which hospital was this and what sort of treatment did they give you?
TM: That was Barcelona initially, Martorell so it's near Barcelona. That was for a week and two days, and then they evacuated me to Portugal, where I stayed in for another week. So it was about a week and a half of intensive care and then one week in a regular hospital. Only after three weeks I stood up and started to move, then having this big, big conversion of the eyes meant I threw up a lot, and had severe headaches. That, plus the trauma was very painful and very hard to go through. Every hour I would need to change a patch, because otherwise you would just feel sick like you were drunk all the time. Then you get used to it like anything, but for six months I was seeing double, and then only a month ago I started to recover. The left eye

> **"I COULDN'T TALK, MOVE MY RIGHT SIDE, FEEL MY RIGHT LEG, I HAD NO SPEECH, COULDN'T SWALLOW LIQUIDS, AND I COULDN'T SEE"**

recovered faster, the right one took longer and this is the one that is taking a little bit longer still.

A+M: So when did you change your mindset? At four weeks was it 'I just want to get better' or 'I want to return to racing?'
TM: My first thoughts were to go back racing! It was crazy. In some cases I know that some people think 'I've had enough' and that 'this is a sign, lets stop it' - I didn't take it like this, I wanted to go back racing from day one. But that's also what helped me go through all the work and treatments. We did a lot of travel and went to a lot of doctors, and I think that was the motivation behind all of that. I was leading the championship at the time and I had that goal in my mind that I wanted to go to the next race, even though most people thought it was impossible. So to have these goals, they were really unrealistic but that's what was giving me the energy to keep on moving.

A+M: What kind of things were you doing to help?
TM: From the basic osteopathy's we then did forty or sixty hours of hyperbaric chamber, breathing pure oxygen for two hours a day to help regenerate cells. We did a lot of work with the eyes, with some machines and also with some basic tools to help exercise the

eyes. I went to the USA in San Diego for head traumas, where six-to-eight hours a day you would be on a drip sitting there and getting these two litres of vitamins and amino acids and stuff like that. I also went to Florida to get an injection in my spine with like a super, kind of anti-inflammatory product. It makes it regenerate faster and I did also therapy in my blood, so I got a blood transfusion almost. We also did all of the physical training a lot, but the eyes and brain were the most important things.

A+M: Were there any particular doctors or physios that you worked with during this time?

TM: The team physio helped me put together a good group of specialists, but then I was also lucky to get the doctor who is in charge of the Portuguese hospitals to choose the best neurological doctors. Then I went to the USA and stayed in two different places. I went to Japan, Germany, and Spain where I saw one of the best optometrists doctors in the world. [MotoGP rider] Marc Marquez gave me his name, because he had a similar thing but just in one eye, so I went to see him. I was really in good hands, in my head I was like 'Even if I don't race again, I don't want to leave with the thought that I haven't done everything I could, so I'm lucky that I'm in this situation and had a great group of people. Then you have the nurses who took care of me, some of them were really helpful – not just the way that they talk to you but the way they treat you. Support is really important because you're in such a weak state of mind, that you can easily go into a downward spiral, psychologically just get depressed and lose motivation. The amount of messages I received, it was such a motivation, getting

Monteiro underwent numerous tests on his eyesight

Monteiro was determined to make a full recovery

"SUPPORT IS REALLY IMPORTANT BECAUSE YOU'RE IN SUCH A WEAK STATE OF MIND THAT YOU CAN EASILY GO INTO A DOWNWARD SPIRAL"

Monteiro spent 40 to 60 hours in a hyperbaric chamber

sent videos from people in the motor sport world who I hadn't seen in 10 years or 15 years. It was really, really strong support to help me move forward.

A+M: So then you've finally made it back to the point where you would go back in the car, how did that feel?

TM: The first time it was way too early, I couldn't see so it was really bad. It felt as if I had double and blurry vision so it was not possible, then a month later I did another test in Monza, which was much better. I would get to a certain lap time because I would get the feeling for it and I could see very well.

A+M: What advice would you give to other drivers who go through tough injuries?

TM: Well one thing is get good insurance. A lot of drivers that I know, if they don't have work contracts they won't get insurance. That's really stupid and dangerous because it's so easy to have an accident. But the main advice, apart from physical pain, is that it will be very, very psychologically difficult to accept that you're not driving. I didn't know if I was going to be driving again, but the main thing is to never, ever give up. You always need to be thinking that whatever happens, you will find a way to overcome it. It feels easy to say it now, but that's what I've been through. I didn't ever think about not coming back, that was my strength I think. So even when you can't talk and can't swallow water or liquids or solids, you still need to think, in a few weeks or months, I will be there.

After sitting out the 2018 season, Monteiro plans to return in 2019

AUTO+MEDICAL SCIENCE

SCIENCE

LITERATURE REVIEW OF RACE DRIVER FATIGUE MEASUREMENT IN ENDURANCE MOTOR SPORT

Fatigue is a common issue amongst sports car drivers who race for long hours without breaks. This literature review explores that and the solutions that could be implemented in the future.

Authors: Nick Owen, Horace King, Matthew Lamb - Victoria University Research Group

AUTO+MEDICAL SCIENCE

Australia's circuits have environmental factors that demand more from drivers

ABSTRACT

Driver fatigue in endurance motor racing has been problematic for driver safety and optimal performance. Historically the focus in this sport has been primarily on improving mechanical performance; making the racecar light, faster and improving grip (aerodynamics and suspension geometry). Driver safety has come secondary. A series of fatal accidents that were attributed to fatigue have led to rule changes; however, these were made with little understanding of the driver fatigue (type/level). As the literature indicates, few publicly available studies into driver fatigue take into account all of the identified stresses for endurance motor racing. Technology has progressed where it is now easier to self quantify with the use of appropriately selected and placed sensors. This literature review aims to highlight the need for sports engineers to develop a new electronic system for fatigue measurement in endurance racing and is the first part of a major research project in the development of a system for race driver fatigue measurement.

INTRODUCTION

Motor racing has evolved well beyond being a recreational pursuit; it is now a multi-million dollar sport demanding the highest level of physical and mental fitness similar to that of any other athlete. Endurance drivers, like the cars they drive, are complex from a physiological perspective. However, unlike the cars they drive, driver-athletes have not been comprehensively examined, evaluated, and tuned to the same degree. Wearable health-monitoring systems are becoming very popular, especially in enabling the non-invasive diagnosis of vital functions on the

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human body [1]. The purpose of this review is to present literature relevant to driver fatigue in endurance motor sport and state the design direction towards the development of a new type of electronics system to be used in the quantification of driver fatigue.

REVIEWED LITERATURE

In this section a review of the most relevant literature to racing driver fatigue, monitoring and detection is presented.

2.1 The case for driver science in motor sport: a review and recommendations

A review carried out by Potkanowicz and Mendel has shown that the influence of stress and strains exerted on race drivers is not well understood or the combined effect is not known [2]. While trainers and sports scientists 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 training principle of specificity [3]. 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 [2].

2.2 Bioenergetical and cardiac adaptions of pilots to a 24h-team kart race

Fatigue along with excessive speed and alcohol is the main factor in road accidents in the general community. In motor racing, when the drivers are highly trained and adapted to the condition, fatigue is known to compromise final performance by lowering anticipation movements affecting force exerted to control vehicle trajectory [4]. Furthermore, the lack of precise recommendations on maximal driver duration in relation to vehicle type, exposes the driver to potentially dangerous levels of fatigue, which may cause crashes [4]. Durand studied heart rate (HR) over the course of a 24-hour go-kart race at Le Mans, France. The research aimed to statistically correlate driver HR with energy expenditure (EE) of the driver. The research concluded that driving a kart for 45 minutes before driver change at around 60 km/hr resulted in a 300 kcal EE, corresponding to a 5.6 Mets (Metabolic

A 24 hour kart race at Le Mans was examined to measure fatigue

> **"FATIGUE CAUSED BY EXTENDED HOURS OF DRIVING A CAR HAS CONSIDERABLE INFLUENCES ON ALERTNESS AND PERFORMANCE"**

Excessive exposure to Carbon Monoxide can increase sweat rate and dehydration

Equivalent of Task, energy cost of physical activities). This effort is responsible for 73+ beats per minute (BPM) increase in HR, reaching 82% HR maximum intensity (157 BPM). These high values were repeatable between each successive driving instance, but not statistical enough to prove that increased HR induced physiological fatigue. The research also reported they did not take into account effects of vibration on the whole. The researchers did not evaluate the combined effects or the frequency of vibrations the driver reported, and a role for this factor on EE elevation and fatigue development cannot be eliminated [4].

2.3 Influence of vibration on vehicle occupant fatigue

Fatigue caused by extended hours of driving a car has considerable influences on driver alertness and performance, which therefore can lead to a compromise in transportation safety. However, fatigue caused by vibration is not well investigated or reported in the available literature. The relationship between vibration magnitude and vibration frequency of vehicle occupant and associated fatigue has been established without sufficient research. This is because fatigue is a complex phenomenon, and there is little quantitative data in existence characterised specifically to motor racing [5]. Research by Amzar and Fard proposed that low-frequency vibration might induce drowsiness and cause a reduction in alertness [5]. To test the hypotheses an experiment was conducted where ten individuals, one by one, were secured into a seat that was mounted to a vibration shaker table that was configured to vibrate in a frequency range of 1-15Hz, with vibrations intensity levels limited to 0.3 m/s, 2 Root Mean Square (RMS). An electroencephalogram (EEG) headband was placed on the test subjects. Beta and theta brain activity was observed in the frequency domain utilising Fast Fourier transformation (FFT) and power spectral density (PSD) within each of the brain activity bands. The results of the study for all ten subjects found that the measured beta brainwave activity, which indicates alertness level, decreased in both random and sinusoidal excitation. However, the drowsiness effect in sinusoidal vibration was more pronounced compared to random vibration condition. The test methodology was a good indication that vibration is a contributing factor to drowsiness and mental fatigue. However, the environment protocol was not realistic as the test participants were not stimulated in the same way a driver would be operating a motor vehicle (the participants were asked to sit comfortably with their back on the backrest and hands on their laps) [5]. As the environment was not replicated then it would be difficult to deduce if the effects of fatigue were induced by vibration or lack of mental stimulation.

2.4 The Clipsal 500 Studies; (CO), dehydration and heat stress

Australia's race circuits such as the Adelaide Street Circuit include environmental factors such as high temperature, high solar radiation, and low wind which when combined with Carbon Monoxide (CO) from race car exhaust gases, exert unique physiological demands on motor sport

participants [6]. AIMSS researchers made observation of a control group of drivers at the Australian V8 Supercar championship (Clipsal 500, Feb 2008). Measurements were made in cabin temperatures, CO levels and driver specific effects, such as fluid loss due to dehydration and body core temperature. Driver cabin CO levels were above 100ppm for significant periods of time (up to 15mins). Although the research indicates several metrics for evaluation, it falls short on quantifying how each of the metric (CO, body temperature, hydration) affects the driver. Excessive exposure to CO can cause acute disturbances highly relevant to the task of controlling a racing car, including impaired coordination, reduced accuracy in determining a vehicle's position, slower reaction times and impaired ability to attend to multiple tasks. CO also increases sweat rate and temperature rise, thus increasing the effects of hyperthermia and dehydration on psychomotor performance. Dehydration is fluid loss due to the normal functioning of the body, mainly via perspiration and breathing. It increases susceptibility to fatigue and muscle cramps. Inadequate fluid replacement before, during and after physical activity causes dehydration, which may lead to fatigue, heat exhaustion or heat stroke. Optimal hydration levels are vital, not just for motor sport participants to perform at their best physically and to maintain mental function; they also help ensure safety and maintain long-term general health [6]. Driver weight changes for Race 1 and 2 showed mean losses of 1.5% and 1.8% of body mass, respectively [7]. There was considerable variation, which indicates some drivers were drinking sufficiently during the race to match sweat loss, other were not [8]. This suggests that there is a need to capture driver fluid intake, to better understand the relationship between hydration and the fore mentioned stresses. Additionally the study above totally neglects the contribution of whole body vibration, as the study was focused on the effects of CO, hydration and temperature awareness.

2.5 Don’t sleep and drive – VW’s fatigue detection technology

Fatigue in general is a very complex phenomenon; 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. Around 20% of fatal road accidents involve driver fatigue. According to VicRoads, around 30% of severe single vehicle crashes in rural areas involve the driver being fatigued [9]. In an attempt to tackle this problem automotive manufacturers have developed driver fatigue monitoring systems for consumer vehicles [10]. An example of such a system is the Driver State Monitoring System developed by Volkswagen (VW). VW researchers identified human error to be a casual factor in many public road accidents. Human error is explained by shortcomings in perception, interpretation of information, decision-making, information recall and direct performance of an action. However, general physical and cognitive aspects such as attention and fatigue also play an important role, because they affect other cognitive processes [11]. When drivers are tired, they fail to take action to avoid an accident. This is especially the case of incidents requiring braking or steering inputs. Fatigue impairs perception and the ability to make the decision to react, and it also degrades the performance of the action(s).

VW summaries the effects of psychological fatigue into four categories:

- Physiological (regulation of the vegetative and nervous system)
- Cognitive (perception and information processing)
- Motor (behavior)
- Subjective (experience)

Table 1. Classification of fatigue category and effects

CATEGORY	FATIGUE EFFECTS
Physiological	Reduced psycho-physiological simulation
Cognitive	Reduction in alertness and vigilance Informed processing and decision-making takes longer
Motor	Reaction time increases when critical event occurs Control reactions are more variable and less effective Reduced preparedness to react

There are difficulties with the methods that are used to assess the drivers’ state and fatigue level in particular. This in turn creates a problem when an attempt is made to test

the suitability of fatigue recognition technology. The VW Driver State Monitoring System implements a non-intrusive observational approach: blink rate, head movement (nodding) and eye pupil position. The system uses two dashboard-mounted cameras focused toward the driver's face; a detection algorithm processes the data to determine the likelyhood of the occurrence of a micro-sleep or abnormal driver distraction. If the system detects any of the three indicators of fatigue, then it will alert the driver with audible / visual alarms [11]. The VW type system is an effective and efficient tool in combating fatigue in medium to long road trips in consumer motoring. In motor sport the driver is a trained athlete and the likelihood of the driver experiencing the same type of fatigue, or pre-fatigue such as lack of sleep or stimulation, is minimised if not eliminated by professional athletic preparation, as the stressors and strains placed on the driver in motor racing are caused by environment, rather than sleep debt. Additionally the driver's race safety equipment, such as helmet, head restraints and fire retardant balaclava, render optical tracking and facial feature recognition inoperable.

LITERATURE CONCLUSION

Endurance motor racing is a team sport that requires the driver, the car and the team to be at the peak performance [12]. The technology currently used in motor racing is well suited to measuring electro-mechanical phenomenon of the car and logging the data for further analysis, but is not designed to specifically interface with the driver or identify the occurrence of driver fatigue. More research is required to further understand the complex relation of driver fatigue in endurance motor sport. What makes an effective and efficient system for consumer vehicles, does not necessarily translate to the world of endurance motor racing. Understanding the athlete and the environment is of vital importance, and the differentiating factors of how an endurance racing fatigue monitoring system shall operate and what should be the inputs for fatigue detection algorithms [13]. By examining the literature, it becomes evident that heart rate, respiration, carbon monoxide levels, hydration, temperature, and whole body vibration are contributors to a driver's physical and mental fatigue in motor racing. Despite this no studies have implemented an approach that allows the combined effects of all the stressors to be established. Ongoing work conducted by the authors focused on the development of an electronic system, which integrates and logs relevant sensory input, designed specifically for the driver and the environment. It is hoped that the research will lead to the development of a tool that can be used to allow for further research towards developing an understanding of the complex relationship between the stressors and driver fatigue.

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