INTERNATIONAL JOURNAL OF
MOTOR SPORT MEDICINE
ISSUE#23, AUGUST 2021

AUTO+ MEDICAL

TARGET PRACTICE

How the FIA targets off-the-shelf safety products and puts them through their paces to ensure they remain worthy of approval

CONTENTS+

GLOBAL NEWS/

FEATURES/

SCIENTIFIC ARTICLE/

Editor: Marc Cutler
Deputy Editor: Rory Mitchell
Designer: Cara Mills

We welcome your feedback: automedical@fia.com

AUTO+MEDICAL

INTRODUCTION/

In this latest edition we follow FIA Head of Competitor & Road User Safety, Nuno Costa, as he tests off-the-shelf motor sport safety products like HANS and harnesses. This is an important part of ensuring that each product is worthy of FIA-approval, which is why competitors should always look for the official hologram.

Following his recent test with the Alfa Romeo Formula One Team, current F2 racer Theo Pourchaire discusses the crash during the Azerbaijan race where he sustained a broken Radius in his left arm and the subsequent recovery for the next round in Silverstone a month later.

There is a look inside the new Mini Pacesetter Safety Car that was introduced by Formula E this season, and Driver Bruno Correia discusses the equipment used in the first all-electric Safety Car used by the world championship in its seven-year history.

In keeping with electric motor sport, Chief Medical Officer for the recent London E-Prix, Dr Dhushy Surendra Kumar, is the subject of the latest Big Interview. Dhushy gives us his insight from working in motor sport for the last 30 years as a critical care consultant.

You can read about the latest safety features in the Gen 2 Formula 4 car, and about Dr Terry Trammel being awarded the Louis Schwitzer Award for his pioneering work in biomedical engineering.

Our scientific article looks at how female drivers can optimise their seating position to improve their on-track performance.

The Editorial Board

GLOBAL NEWS

NEW SAFETY FEATURES ON GEN 2 FORMULA 4 CAR

The new Gen 2 Formula 4 car features the latest in safety developments from the FIA that will benefit drivers in National F4 championships around the world.

These championships are the first step out of karting into cars for young drivers at various stages of physical development, which means it can feature teenagers as young as 15 racing against adults in their mid-20s.

This is why the latest Gen 2 car has been designed to incorporate three seat-shell sizes to optimise safety for all statures. This offers more ergonomic flexibility to accommodate different driver sizes and increased visibility to ensure maximum accessibility.

The survival cell has been upgraded to be in line with the most up-to-date safety standards, providing more protection and support for a driver in a side impact. To achieve this, stringent load tests will be implemented for the survival cell side strength and the side and frontal anti-intrusion panels of the new car.

The gaps between the extractable seat shell and chassis are filled with a pre-determined size of foam “outsert,” ensuring that impact energy is distributed over a wider surface.

FIA Formula One Race Director and Single Seater Sporting Director, Michael Masi, said: “The second-generation F4 car has been carefully developed by the FIA and its suppliers and partners to offer a significant upgrade in the key areas of safety and performance whilst remaining cost-effective for championship organisers and competitors.”

Combined with the headrest and survival cell, this offers optimal protection for drivers in the most junior of the FIA’s single-seater categories.

LATIFI SUFFERS FROM DEHYDRATION DURING MONACO GRAND PRIX

Nicholas Latifi suffered from dehydration during the Monaco Grand Prix, after forgetting to connect his drinks tube before the start of the race.

Every Formula One driver has a drinks tube that feeds into their helmet, which enables them to have a drink of water or isotonic drink during the race to replenish lost salts through sweat and stay hydrated.

After tackling the bumpy Monaco street circuit and climbing from 18th to 15th, the Williams driver said he felt dehydrated when he got out of the car.

“I think the only mistake I made was before the race even started, I forgot to put the drinks tube in my mouth! I didn’t realise until afterwards,” said Latifi. “I just downed [a drink] after I got out of the car, but it was fairly straightforward.”

Drivers usually train to ensure that they don’t suffer from severe dehydration during a race, which is why Latifi was able to emerge from the race without any problems.

“We train for it. It’s not ideal, I was probably a bit dehydrated after that,” said Latifi. “You don’t really get much of a rest around this track, even in the straights you’re turning and probably the extra mental energy that goes into Monaco makes you work a bit hard.

“Consider that it’s also my first time in Monaco so it’s maybe going to be a bit harder for me than it is for a guy like Lewis or Kimi that has done so many races around here. But yeah, I train for it. I was fine.”

F1 TECH PUT TO USE IN LEICESTER’S HOSPITALS

A pioneering new device that will be used to help doctors and nurses communicate clearly while wearing Personal Protective Equipment (PPE).

Developed by Leicester academics in collaboration with Formula One race engineers at the Alpine F1 team, the MedicCom uses a throat microphone to pick up and amplify sound which enables patients to better hear the medical staff who are caring for them.

Being able to hear medical staff can often be an issue when they are covered in head-to-toe PPE worn when treating patients with COVID-19 and other infectious diseases, causing them to have to shout to be heard properly.

This not only leads to increased exhaustion but can also cause errors of miscommunication which could potentially harm patients. MedicCom enabled doctors and nurses to hear each other more clearly, and also links to their mobile phones via Bluetooth so they can hold a clear conversation with a patient’s relatives.

Tim Coats, Professor of Emergency Medicine and Associate Dean for Clinical Data Science at the University of Leicester, said: “Good communication has a profoundly positive effect on patient care, and that is why we started work on a solution. Working with the F1 engineers has been brilliant.

“We’ve been able to use their expertise in advanced electrical engineering and their facilities for rapid prototyping to produce in six months a device which would normally take years.”

PEREZ STRUGGLED WITH SHOULDER PAIN DURING SPANISH GP WEEKEND

Sergio Perez has revealed that he had pain in his left shoulder during qualifying for the Spanish Grand Prix.

When setting a lap time during the final part of the session, the Red Bull driver spun on his first attempt and then could only manage the eighth best time. Perez was not sure how he sustained the injury but noted that the pain got worse during the session.

“I had a bit of an issue with my shoulder through qualifying and was feeling bad all the way through it. I wasn’t 100 per-cent, so it was hard to get the best out of the car in qualifying. It was the toughest qualifying and not feeling 100 per-cent physically was a big limitation.”

Perez didn’t feel the pain was caused by his seating position and explained that he didn’t do anything to exert himself in a strenuous way that would’ve caused it.

“It was just getting worse and worse as qualifying developed. I struggled with a bit more with it. I don’t think it’s something I’ve done with the car,” said Perez. “We don’t know 100% what it is, but we’re pretty confident that we can be back to form for the race.

SAFETY THE MAIN DRIVER BEHIND NEW GEN3 SUPERCARS CHASSIS

The new Gen3 Australian Supercars chassis will have a number of enhanced safety features, which will help protect drivers in the event of a crash or incident on track.

The key advancements made to the safety cell include a seating position further away from the door for the drivers, and there will be a small hatch for to aid medical and extrication crews during a major accident.

"We're always looking at what's new on the market, and how we can build a safer chassis for the drivers," said Supercars Head of Motor Sport Adrian Burgess. "We've taken that into consideration; the position the driver will be in the car, they'll be further away from any side-intrusion.

"We've incorporated a hatch in the roof; for clarity, it's not an escape hatch. You won't be able to physically pull a driver through the hatch. It's more to enable the extraction and medical teams to have better access to a driver in the wake of a big accident."

The hatch is designed to help responders put neck and back restrains on the driver or remove their helmet, so they can be stabilised before they are extricated from the car through the door.

The new chassis will also see incremental improvements on existing systems, including leg protection. There will be greater protection across the top of the drivers legs and from the steering column.

THEO POURCHAIRE INJURES LEFT ARM IN BAKU F2 CRASH

Theo Pourchaire injured the bones in his left arm following a crash in the Formula 2 feature race in Azerbaijan.

The F2 racer was pincered between Dan Ticktum and Marcus Armstrong going into Turn 3, with the impact causing Pourchaire's steering wheel to snap whilst he was still holding it in his hands and exert forces onto his arm.

After the race he was taken to The Central Hospital of Oil Workers, where he received treatment for a fractured arm. Speaking on social media, Pourchaire confirmed that he broke the left radius in his arm.

"Just wanted to tell you that I'm fine, yesterday as soon as the plane landed, I went straight into a special clinic in Monaco," said Pourchaire. "I have the left radius broken; it is really painful but it's ok.

"I have my arm immobilized for 4 weeks from now, I will give everything to be back soon," added Pourchaire. "I don't know yet if I will be driving in Silverstone, but I will work hard and pray to be ready."

You can read about Pourchaire's injuries, how he prepared for the following round in Silverstone, and his ongoing recovery in our 'Road Back' interview on P30.

KARTER USES MOTOR SPORT FOR BENEFIT OF MENTAL HEALTH

Elliott Shaw has been creating success on the international go-kart scene since 2016, while also suffering with Asperger Syndrome and ADHD.

The 18-year-old Swiss-born driver has English parents and has been karting in national events since 2012 and made the jump to the adult X30 Elite series in 2017. Last year during the ROK Superfinal, Shaw started from the front row and was running in the top three for most of the race.

The process of competing and racing has raised his self-belief and confidence to overcome adversity according to his family, who believe Shaw is empowered by the challenge to exceed the expectation of others of his ability.

"Elliott has a great desire to create an appreciation of the possibilities motor sport offers for people like himself with Asperger's and general mental health issues, the objective being to overcome any stigma and the associated challenges and to encourage others to believe that great things can be achieved," said his father, Andrew Shaw.

AUTO+MEDICAL GLOBAL NEWS

F1 DRIVERS JOIN INAUGURAL AIMSS SAFETY SUMMIT

The inaugural Australian Institute of Motorsport Safety (AIMSS) Motor Sport Safety Summit was held virtually in June, which featured several presentations ranging from safety, rescue, and medical topics.

The Summit has attracted a large panel of internationally renowned motor sport personalities, including two-time F1 champion and Alpine driver Fernando Alonso, alongside former F1 drivers Mark Webber and Romain Grosjean.

Grosjean talked the panel through his infamous 2020 Bahrain Grand Prix crash and how the advances in F1 safety saved his life. There was an examination of the critical decisions and how they are made during a motor sport Rally incident, and the unique challenges posed by remote locations. A panel also discussed keeping grassroots motor sport safe, and the equipment used by professional motor sport organisations.

A 'Pitch my Project' session enabled four individuals or groups a chance to pitch their motor sport safety-related project to a panel of motor sport experts including AIMSS Chairman, Garry Connelly, Sam Michael, and Rik Hagen.

"The AIMSS Motorsport Safety Summit is a wonderful initiative that will help further showcase the skills, technology and ingenuity of those working tirelessly to improve safety in our sport," said AIMSS Chairman, Gary Connelly.

"The Summit has attracted an international faculty representing the Asia Pacific region, who are all invested in progressing motor sport safety."

HOLMATRO LAUNCH ONLINE TRAINING WEBINARS

Holmatro has launched an online training webinar that enables rescue workers to learn about the use of their tools in a variety of vehicle extrication scenarios.

The Holmatro Online Training (H.O.T) sessions can be attended free of charge by signing up online and are hosted by Holmatro Rescue Consultants, Ronald de Zanger and Marinus Verweije.

The training webinars are based on the input of first responders, where they can propose topics and ask questions during sessions live streamed online. Each session combines theory with practical hands-on tool work on a car, in a specific scenario including passive safety systems, quick vehicle

stabilization and glass management.

Both de Zinger and Verweije are volunteer firefighters who have also fulfilled instructor positions within their respective fire departments and can rely on a strong background in extrication rescue. Since Holmatro's partnership with the FIA, de Zinger works closely with FIA Rescue Specialist, Ian Dunbar to support the FIA's motor sport safety goals.

Readers can attend these sessions by signing up at http://bit.ly/holmatro-webinar and can submit their topics of interest through http://bit.ly/holmatro-mr.

TRAMMEL RECEIVES AWARD FOR INDYCAR SAFETY

Dr Terry Trammel, Safety Consultant for IndyCar, has received the Louis Schwitzer Award for his pioneering work in biomedical engineering.

The annual award is named after Louis Schwitzer, an automotive engineer who won the first race at Indianapolis Motor Speedway in 1909, and is presented to innovative engineers who have develop cutting-edge concepts that increase safety, performance, or efficiency of Indy 500 race cars.

Trammel's numerous contributions have helped advance driver safety in IndyCar and prevent driver injuries, by utilising a data-driven approach, engineering principles and medical expertise. As such, his efforts have been recognised across multiple motor sport safety organisations throughout the world.

"I'm very honored to have received this," said Trammell. "I want to express my appreciation to the Louis Schwitzer Award committee for awarding me this honor. It was unexpected, to say the least. I want to thank Borg-Warner for sponsoring.

"When you really think about it, a large number of orthopedic surgeons have an engineering background. One of the core principles throughout an orthopedic residency is regular education in biomechanics. When you're putting hardware in people, it's a good idea to know how heavy the hardware has to be, how many screws, how long a plate, what kind of material, so on and so forth. Without really knowing that's we're doing, that's what we do every day."

DR DHUSHY SURENDRA KUMAR

CONSULTANT IN CRITICAL CARE

Dr Dhushy Surendra Kumar is a critical care consultant who has been part of the motor sport world for over 30 years. Alongside his commitments working in Critical Care, Anaesthesia and Pre-hospital Care at University Hospital Coventry, he has served as Chief Medical Officer (CMO) for a number of grassroots and FIA World Championship events including the recent Formula E London E-Prix. He speaks to *AUTO+ Medical* about his experience.

AUTO+ Medical: What came first for you, motor sport or medicine?

Dr Dhushy Surendra Kumar: My Dad has always been into cars and so was I growing up, I just loved talking cars and helping him to choose his cars. My first car was a TVR Griffith and 60 per-cent of my salary went onto my car, which is stupid but gives you an idea of how much I like my cars. Always been into cars, enjoyed motor sport, and then medicine was a career that I went and chose but then I found out I could mix the two when I was in Bristol. There was a guy called Alistair Dow who used to work at Castle Combe who introduced me to Jerry Nolan and Peter Baskett, and I learned alongside them about motor sport medicine. Started to enjoy that and then I was then invited to do the British Grand Prix in 1994 and I haven't looked back since.

A+M: How much of your experience in medicine have you carried over to motor sport or vice versa?

DK: I went into Anaesthesia and Critical Care, and what we now know as 'Pre-hospital care' which is a speciality in its own right – we didn't really call it that back in the 90s, but it's become a speciality in its own right. Managing critically ill patients, be it roadside or trackside, it turns out that was one of the more useful specialities to have in motor sport, so although we do have a wide range of people involved in motor sport now, it's the pre-hospital consultants that are coming to the fore. We bring those skills that we use every day roadside and it's the same thing trackside.

A+M: What are the roles you've had in motor sport?

DK: I have worked at pretty much all of the circuits around the UK, I was Chief Medical Officer at Rockingham for many years and I setup the Medical Center and medical services for the inaugural Abu Dhabi Grand Prix. I've supported races in Dubai, I get asked along and just sit in the car usually and makes sure everything goes ok, I don't really appear on anybody's radar I just provide the service – which I quite like actually. I've had the opportunity to travel and meet people, get to meet lots of other colleagues in other countries, learn about motor sport in other countries and different cultures and it's been wonderful.

AUTO+MEDICAL FEATURES

A+M: How long have you been CMO for the London E-Prix?

DK: The first two in Battersea I was asked to be Chief Medical Officer for that, and then of course it paused, and we thought about restarting it. Then of course we've had this pandemic problem which put the brakes on everything, but it was a surprise and a delight to get everything up and running.

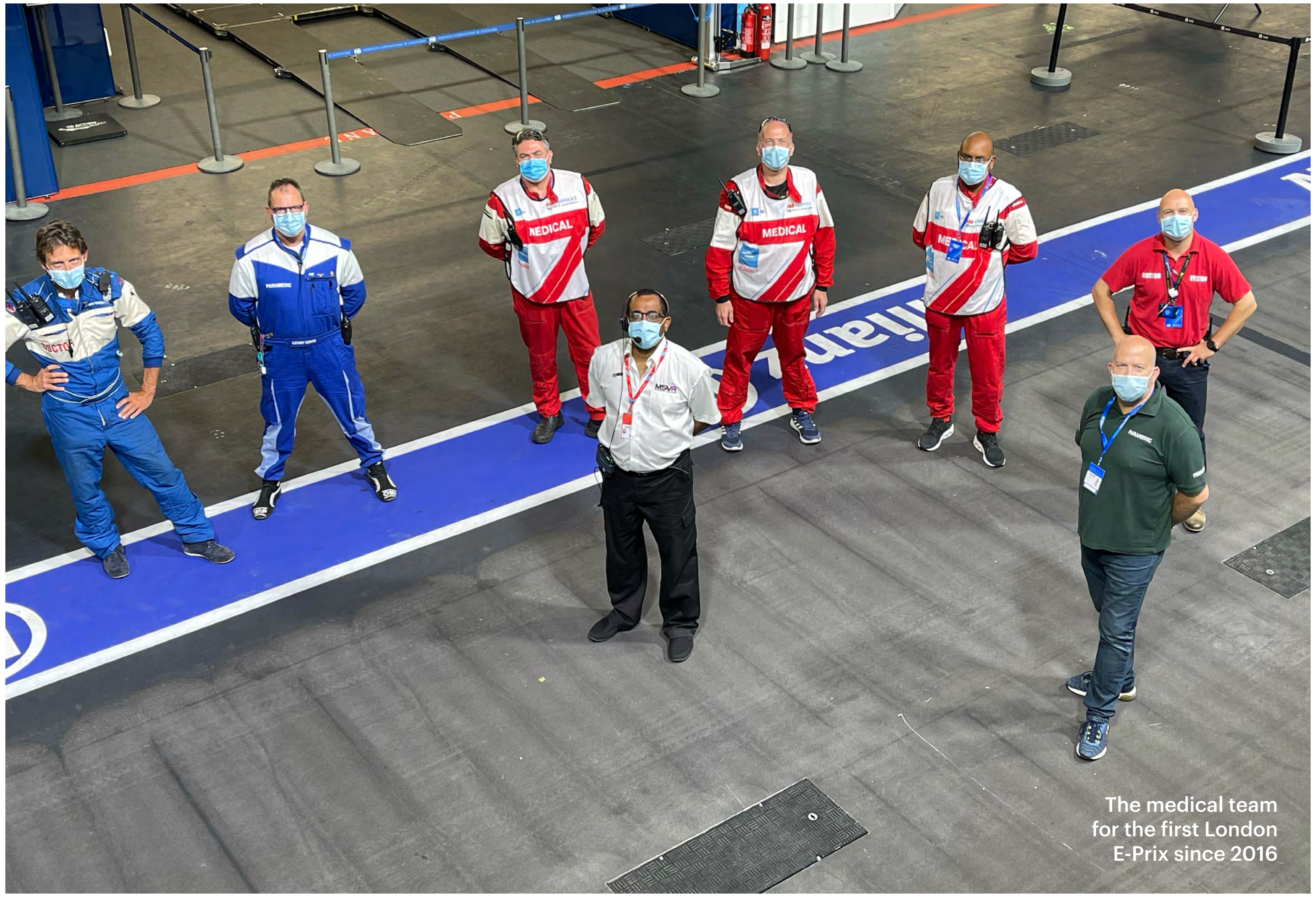
A+M: What are the safety considerations of the circuit?

DK: The indoors and outdoors bit doesn't really change the way we look at it, there are still corners and things to hit. We would approach it like any other circuit, there is stuff going round and there is stuff they can hit, mostly Tecpro. Unfortunately there is water there this time round which adds a little extra to the planning, but we don't have to worry about exhaust fumes because its Formula E and we can run indoors quite safely without having to worry about having to monitor exhaust fumes, emission gasses and so on. I've been doing it so long that it's another circuit and we just put the usual systems we have in place for safety. In terms of preparation the FIA has a good set of structured questions, needs, that you have to apply to any race meeting. You comply with that and that standardises everything no matter where you are.

A+M: Are there any other challenges in Formula E that you've come across medically?

DK: Not as yet. There is the issue of electrical safety which Formula E takes very seriously. We've got good briefing documents and would get face-to-face briefings, although like everything else its virtual now, every year to just refresh everyone's mindset again and each time before the race. That's very useful and this information isn't brand new to anyone, but it just gets everyone attuned to the systems in place. This isn't just one race in isolation, this is a series that goes around, and we need to be able to slot nicely into the Formula E system. We at MSVR work with our partners, MSS locally and MDD who travel around with Formula E and provide continuity of medical services for the paddock. So there is a lot of dovetailing with the other services in the paddock and the main thing is just to make sure that the teams and everyone travelling around with Formula E don't really notice any differences and just see it as exactly what they expect.

> **"I WAS INVITED TO DO THE BRITISH GP IN 1994 AND HAVEN'T LOOKED BACK SINCE"**



The medical team for the first London E-Prix since 2016

A+M: You were consulted during the design of the Medical Center for the Abu Dhabi Grand Prix, what was that project like?

DK: We had to tweak some things in the Abu Dhabi Medical Center. We moved a couple of walls and things just to make it fully compliant and flow nicely. It was nice to be involved in that and get a chance to voice my input. I wasn't sitting there with a pencil and drawing things out in the medical center, but it was nice to get shown the plans originally and comment on that from a medical flow perspective to make it just right.

A+M: How important is that for your job?

DK: Very, I mean when you design a circuit you don't just do it with one engineer designing a circuit, you have a whole range of people within that circuit inputting their needs and the medical center is no different. You need to be getting the people who will be using the product involved in the design.

A+M: You have also worked with marques such as Porsche and Ferrari, which event has been your most challenging?

DK: Yes I've been very lucky, I've had the chance to work alongside various marques. Most recently with Porsche I was able to take part in a trip from Bodø in Sweden to Tarifa in Spain, which was the distance that their Le Mans car travelled. I was invited to take part and provide some support for that trip, and I

have to pinch myself sometimes with some of the things I get to do. It's great working with Porsche, they're a great bunch of people and the journalists were as fun as they always are! It was one of those epic trips you occasionally get to do!

A+M: Biggest challenge working in motor sport so far?

DK: I think that probably was working on the Abu Dhabi Medical Center and getting it up and running, living in the UK and working full-time, having to travel across to make sure everything was ok. To top it all off, they had 12 weeks before the circuit inspection, so we went from sand to inspection in 12 weeks! Which was interesting, a lot of early mornings and late evenings.

A+M: What's the most rewarding aspect of working in motor sport?

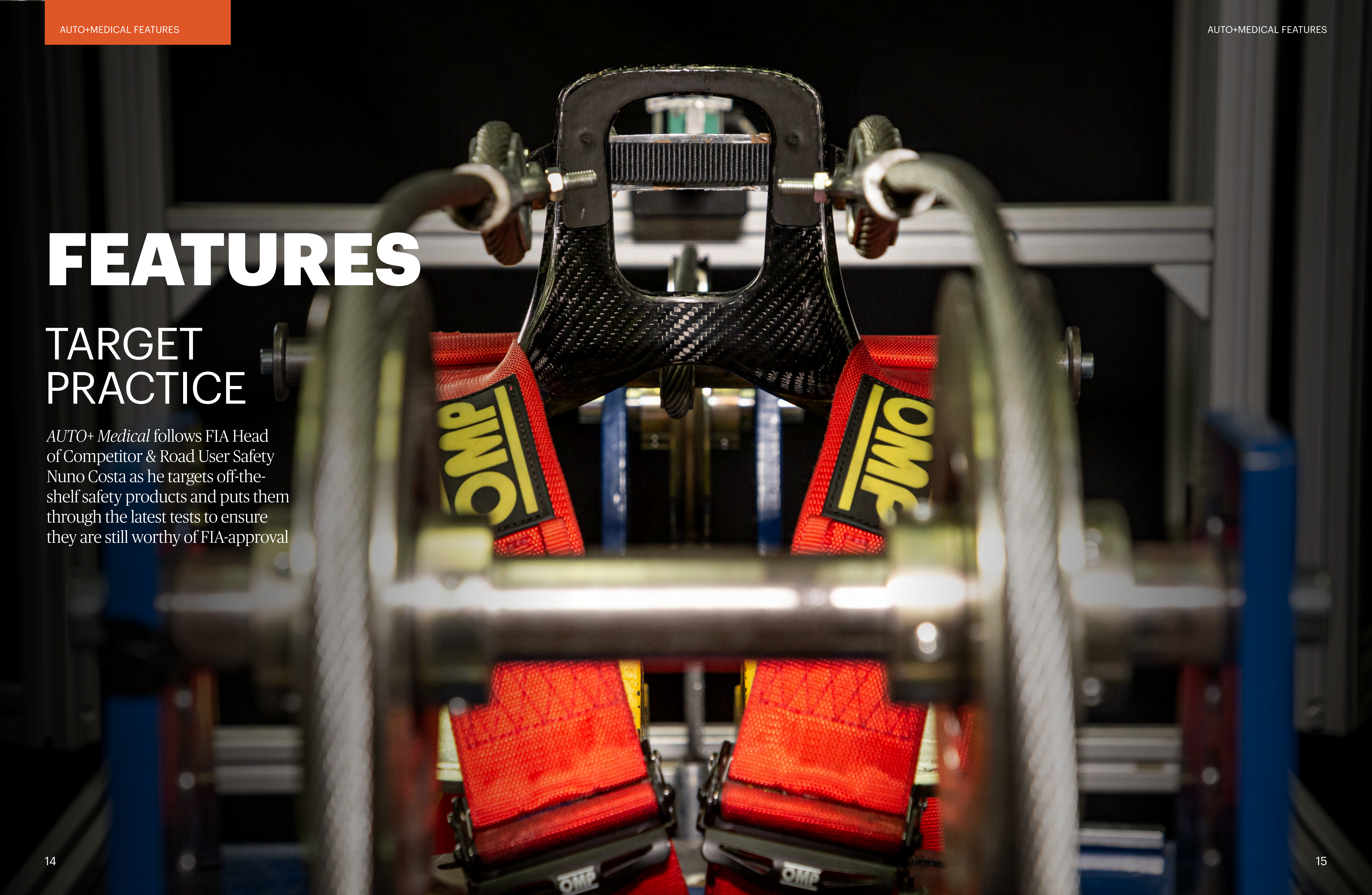
DK: I think it is just fun. The motor sport family are a fun bunch of people, they come from all walks of life, all backgrounds, but there is this common love of stuff that runs on wheels and smells of petrol. That common interest means that it doesn't matter where you are on the weekend, there is something to talk about with the people around you. I meet and chat to people I've never seen before, in a way that you wouldn't elsewhere. Everyone is there for a common purpose, the spectators are always fun, it's a great family event, particularly Formula E when they have the additional areas with family entertainment and educational sites around how to make motor sport and motoring greener, and it really is a very different experience.

A+M: If you could improve anything about motor sport safety, what would it be?

DK: The only way to improve safety is to make it less exciting and you've got to have that balance in the business. As a doctor, I would cocoon them in something where the drivers could bounce off anything and still be 100 per-cent safe but that would be really dull – nobody would want to watch that! There is this balance you've got to strike, and I think having good crumple zones, good systems that shut down the cars whether they are petrol or electric, systems that don't send debris into the crowd. Those are all things that are evolving, and that the FIA take an active involvement in improving. The question will always be ongoing as to whether an open cockpit is safe and I think ultimately, we will head to a closed cockpit for the safety of a driver. Each time we get an injury or a fatality in the sport, we take a good look at something and say: "Should that have been possible?" There have been large jumps in safety and that's what people see, but month-on-month and year-on-year, there are constant tweaks to various safety elements in engineering and treatments we can give medically. It's that constant striving that makes this sport exciting and as safe as we can make it.

The London E-Prix was the first indoor and outdoor circuit for Formula E

AUTO+MEDICAL FEATURES



FEATURES

TARGET PRACTICE

AUTO+ Medical follows FIA Head of Competitor & Road User Safety Nuno Costa as he targets off-the-shelf safety products and puts them through the latest tests to ensure they are still worthy of FIA-approval

On every piece of FIA-approved safety equipment there is a hologram affixed that ensures the product is genuine and complies with the latest safety standards. But how do competitors know that is always the case?

To ensure that every product complies to the strict homologation rules that are defined by FIA Standards, FIA Head of Competitor & Road User Safety Nuno Costa targets off-the-shelf safety products and puts them through a post-homologation process to ensure they remain as safe as when first tested.

Post-homologation tests compare the off-the-shelf product with the original that was tested during the homologation process. The latest of these was done with a Frontal Head Restraint (FHR) from Stand21 which included three tests; two non-destructive and a final one that applies force to the device until it fails.

"If we see during the post-homologation that something has changed outside of the permitted modifications, that is a fail," explains Costa. "There are two types of post-homologation controls; first is a comparitive check, which is to compare the product with the original approved; and the second which is basically to do a standard test or select some tests that are written in the FIA Standard.

"For the FHR its easy because we did all the tests we had in the standard. In some other cases it is not possible to do this because if you imagine a helmet, we need to run at least eight helmets per shell size depending on the standard to do the full homologation. In that case, what we typically do is buy one helmet and then we perform some tests and compare the results."

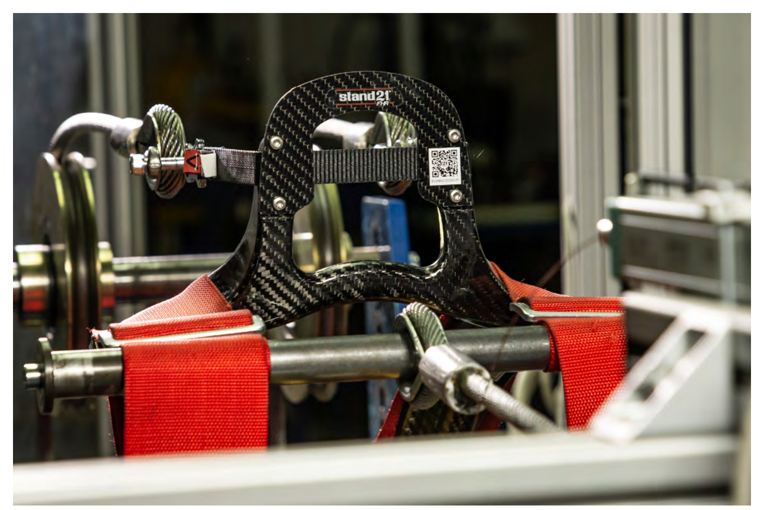
Once a product has passed or failed these tests, Costa goes through the process of informing the manufacturer appropriately. In the case of Stand21, its FHR passed the tests which means they will be sent a letter from the FIA to say the product was bought, tested, and met the safety requirements along with the data to prove.

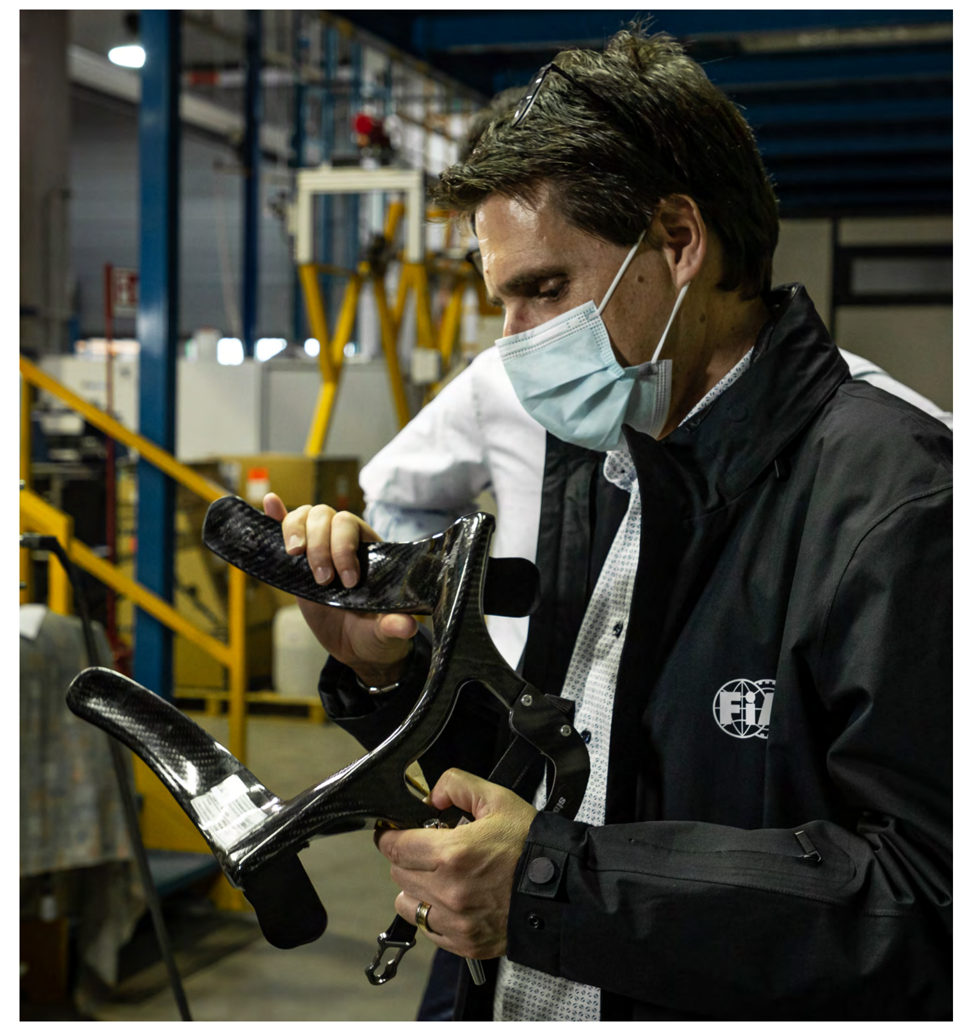
"EACH PRODUCT HAS A UNIQUE SERIAL NUMBER ON THE FIA HOLOGRAM"

When there is a fail, the manufacturer will be given 20 days to inform the FIA if they want to repeat the test whereby a second product is bought and another test date is scheduled. This will be attended by the FIA, manufacturer, a representative from the National Sporting Authority (ASN) of the manufacturer, and the test lab.

"If we identify a specific batch that has a problem or from a certain date of manufacturing, we only recall these products. We then test a product from a previous date to ensure the equipment is safe," explains Costa. "If this passes the tests, then we can still accept those products

Costa puts safety equipment through the same tests required in FIA Standards





and we will recall the ones that do not meet the standard."

QUALITY CONTROL

In some cases, a manufacturer will come to the FIA to report a specific problem found during their quality control processes, which will result in both parties working together to find a solution to remove the products that are not safe anymore on the market.

To make sure the manufacturer's quality control process is up to the standards required by the FIA, and in order for the manufacturers to be able to keep manufacturing the FIA-approved safety equipment, after five years they will need to submit to the FIA a dossier to demonstrate that the safety equipment is still up to the standard by going through a full new test defined by the FIA Standard for the product they are producing or by having a Quality Control system that meets the minimum requirements defined by FIA.

"What happens during these five years is they will do certain tests. If they identify there is a problem and a failure, they will inform the FIA and then we will start an investigation to try to understand why the problem happened and try to find a solution. These discussions normally they are straightforward and very easy, because they took the initiative and know that they have a problem."

If the product still fails the tests, the FIA will start an investigation into why it happened and in the most extreme cases the homologation of the product is stopped, sales put on hold, and an announcement is made to say that it is no longer accepted in competition through FIA Technical Lists.

"Once we finish the homologation, then we strike through the product under the manufacturer in the homologation list, so

"WHEN PEOPLE CREATE FAKE LABELS THEY WILL NEVER BE ABLE TO MATCH THE INFO WE HAVE"

the product is still listed but crossed out and FIA and ASN officials know that the product cannot be accepted anymore when the FIA regulation is in place," says Costa. "We then have a note in the technical list which says: 'For safety reasons, the homologation of the safety equipment is withdrawn with immediate effect'

"If we only stop a certain batch, we will put the product homologation number along with the year/period in the list, enabling the FIA and ASN officials to know it's a certain batch and all the others are allowed. We also issue a communication on the FIA website and send a letter to all the ASNs saying 'this product is no longer valid' because they don't comply with the FIA Standard."

The performance of safety equipment is directed related to a full package of: the minimum safety level and design requirements required in a standard, the administrative requirements such as quality control requirements and post homologation controls and safety features to reduce the probability of fake products to be introduced in motorsport, such as holograms and product full traceability.

SEAL OF APPROVAL

Every piece of FIA-approved safety equipment contains a label that is composed of two parts: the label that is produced by the manufacturer which has their information, the necessary information for competitors and officials to identify the eligibility of the product for a certain competition, such as FIA Standard reference, manufacturer name, homologation number, etc. And the FIA hologram that contains a code for the FIA Standard and a unique serial number.

For example, for advanced racing seats the homologation number will say 'AS' for 'Advanced Seat' and then there are three digits for each model, and at the end there is the year of homologation was assigned. So that would be 'AS.000.00' – every model has a unique homologation number.

"For each product they will have a unique serial number on the FIA hologram and for each unique serial number, we ask the manufacturers to have a complete traceability file," says Costa. "If there is a problem and we identify the batch, then we know for that batch the serial numbers have been assigned to that batch and then we can recall the specific serial numbers.

"It's a little bit like in the automotive industry. If there is a problem with an airbag for a certain batch. They will know which

airbag has been fitted in each car, then for each serial number of the car they know the customer, then they will contact them. We apply exactly the same concept."

While holograms can be copied and used to sell counterfeit products, the FIA Hologram has the same level of security as is used on bank notes to ensure that it nearly impossible to replicate. If a good copy is made, a series of checks can be done by both the FIA and the hologram supplier to check if the hologram is genuine.

"There is the first check we can do which is looking at our database," says Costa. "When people create fake labels they will never be able to match the info we have in our database because only the FIA and the manufacturers have it. The other reason they might do it is to extend the validity date of the products – again if that happens we will be able to know through the database."

All of the holograms are produced by a supplier for the FIA, who then sell them onto the manufacturers. This is done to ensure that these are only used for products that have been approved and passed the homologation tests, so a manufacturer that only homologates seats will not be able to use the labels for additional products they sell such as helmets or FHRs.

"The hologram means that the initial product not only meets the FIA Standard but has been through several processes, the quality control that the manufacturers do, and all these random post-homologation tests that will give them the guarantee that the product meets the FIA Standard," says Costa.

"That's why we say that you should always look for the hologram."

AIMING WIDE

A new app developed by the Australian Institute of Motor Sport Safety (AIMSS) is set to dramatically enhance crash reporting worldwide

Motor sport incident and injury reporting is an important process at all levels of racing and rallying, from grassroots to Formula One.

For many years, it has been a complex and time-consuming manual task involving lots of paperwork, which can lead to crucial information and context being missed.

A new app from the Australian Institute of Motor Sport Safety is aiming to change that.

Founded by AIMSS chair Garry Connelly, the Crashtag app is designed to make the reporting of motor sport incident and injury data seamless and easy, with anyone ranging from marshals to spectators able to submit an incident report.

AUTO+MEDICAL FEATURES

"The idea of Crashtag came about after AIMSS did a review of rally safety in Australia and found that there were a lot of incidents in motor sport, particularly at the lower level, that go unreported," says Connelly.

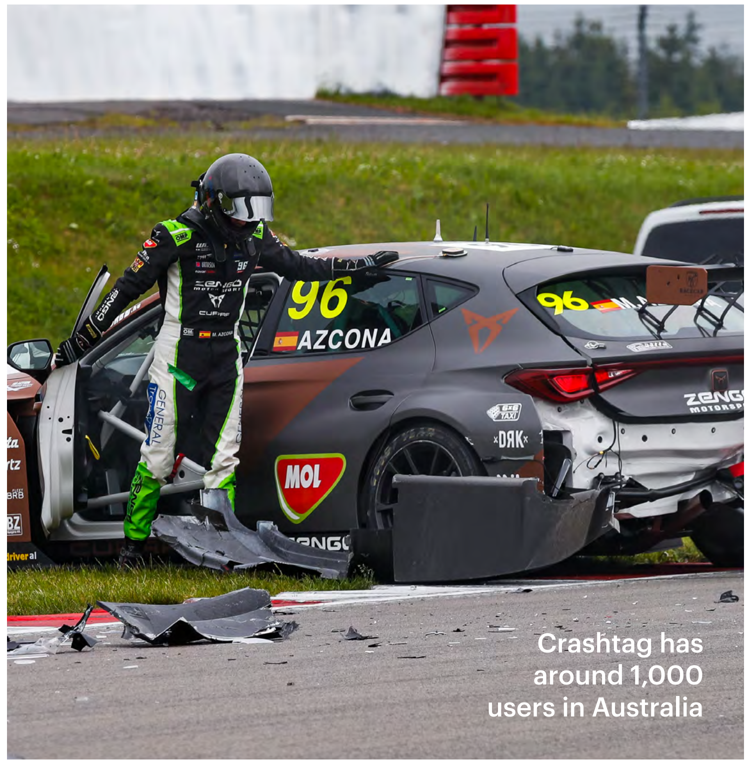
"We also identified that a lot of the reports that are done end up in a box in an office somewhere and never really get analysed because they are in hard copy format with handwriting. Trying to digitise that is a massive effort, particularly for National Sporting Authorities (ASNs) around the world, that don't have a large number of staff."

The app, which received a grant from the FIA Innovation fund, has been developed to eventually work in conjunction with the FIA World Accident Database, which stores data from accidents to be studied by safety researchers. But the initial aim is to roll it out nationally, with the first uses in Australia at the grassroots level.

"The report forms for the World Accident Database that the FIA requires to be completed by every ASN when there is a serious accident, are really quite detailed and lengthy – about 12 pages when you've combined the details of the crash, the initial medical reports, the follow-up medical reports, the vehicle damage photographs and other valuable data including eyewitness reports," Connelly explains.

"What we've tried to do is digitise that and make it so it can be reported on a mobile phone. We rolled that out in Australia, and we've got somewhere around 1,000 users and we're getting a large percentage of the crashes here in Australia reported via the App."

The take-up of Crashtag in Australia has been encouraging, with around 60-70 per cent of accidents now reported through the app, leading AIMSS to propose it to be used in other countries around the world such as the UK, France, South Africa, Sri Lanka, and New Zealand.



Crashtag has around 1,000 users in Australia

"DEPENDING ON YOUR ROLE, YOU HAVE DIFFERENT VERSIONS OF CRASHTAG"

Unfortunately, that process was impacted by the onset of the COVID-19 pandemic, but a trial has been completed at a Formula 4 event in Mexico.

"In some other countries they've used it on some events to test it, in other countries they've just trialled it in desktop mode, so in other words they haven't released it yet," Connelly says. "New Zealand is going to release it publicly in the coming weeks."

Early feedback suggested that the report remained too long to fill in on a smart phone trackside, prompting AIMSS to develop a shortened version which is set to be released next month.

"We've changed the whole format of the form so that it is a lot better than it was three or four months ago, it is a lot easier to use," Connelly explains.

Now the app initially provides a short version of the form, which takes a minute or two to fill out. The user will then be prompted to provide further info if they have it via a more detailed report using either their phone, a tablet or a laptop.

"It will be a lot better for them to sit down either in their environment at home or in the office after the incident and put in all the details that the FIA normally requires for a detailed serious accident report," adds Connelly.

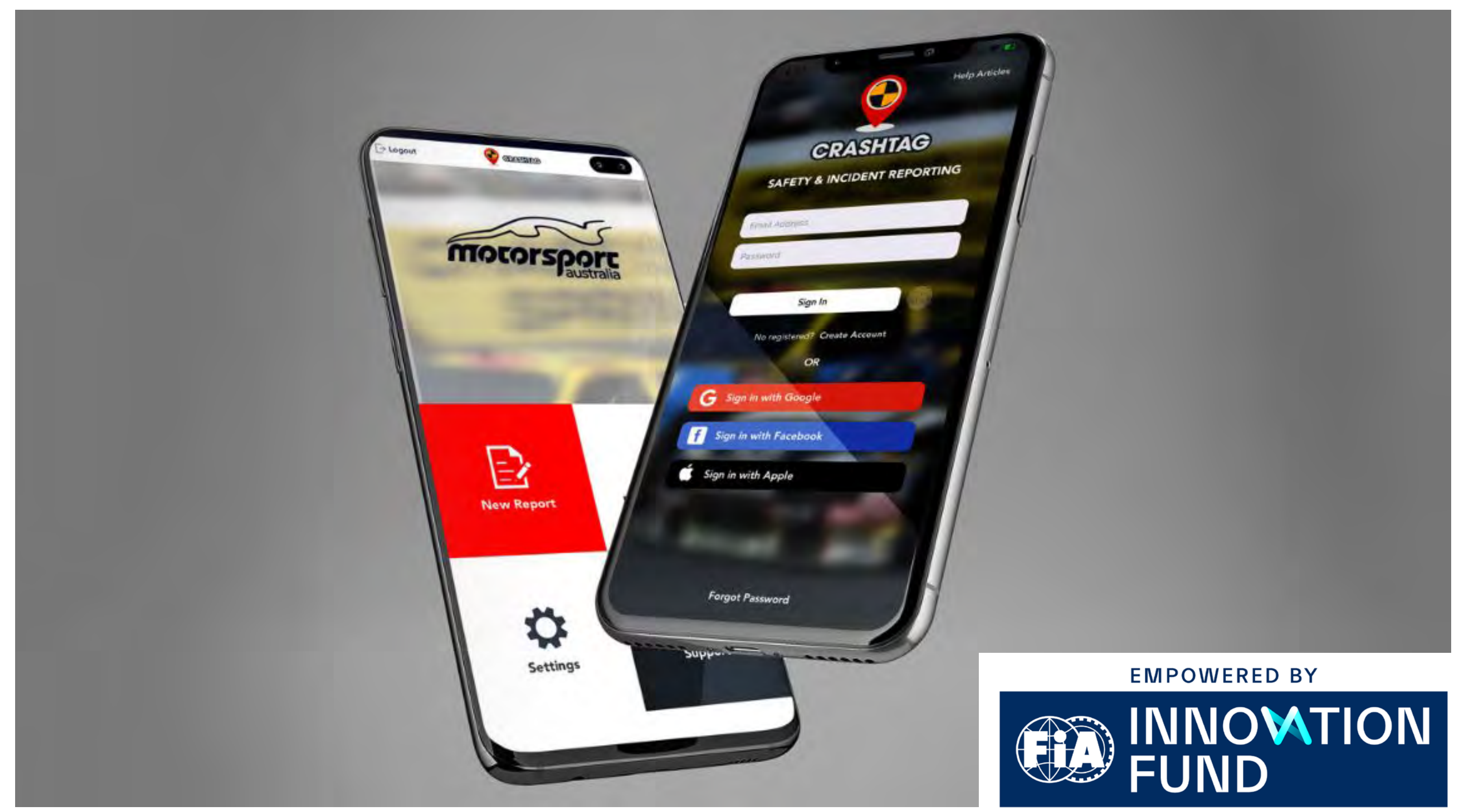
Crashtag is designed to capture as much information as possible, with different versions available depending on the role of the person inputting the data.

"Depending on your role, you have different versions of Crashtag," Connelly said. "So, if you are a scrutineer, you will have the scrutineer's version, if you are a doctor, you will have the medical one, if you're the clerk of the course or the race director you'll have another version, if you're a spectator you'll have a version, if you're a media person you'll have a version.

"We're also going to be encouraging people – which we're doing here in Australia – to report the near misses or the crashes where people walk away, because that way we can analyse what works as well as what doesn't work."

Connelly and his team will continue to develop the app to make the process of reporting as straightforward as possible. That will be the key to unlocking crash data for the benefit of motor sport worldwide.

The Crashtag project is supported through funding from the FIA Innovation Fund, which aims to support new and worthwhile project ideas submitted by FIA stakeholders that benefit and create an enduring legacy for the FIA across its Mobility and Sport pillars. To learn more about the FIA Innovation Fund, visit www.fia.com/fia-innovation-fund.



AUTO+MEDICAL FEATURES

INSIDE THE...

FORMULA E SAFETY CAR

A look inside the Mini Pacesetter introduced by Formula E, the first all-electric Safety Car used by the world championship in its seven-year history.

If you have been watching the last few Formula E races, you will have noticed the brand new and rather striking Mini Pacesetter. The car is the first all-electric Safety Car used in the world championship's seven-year history, after it previously used the hybrid BMW Roadster i8.

As Formula E goes to a lot of tight street circuits and races on public road surfaces with varying levels of grip, the smaller Mini adjusts well to these while keeping with the all-electric ethos of the championship.

Developed in a collaboration between Mini Design, BMW Motorsport, the FIA and Formula E, the purpose-built Safety Car takes inspiration from the performance of the John Cooper Works Mini's and has a number of optimisations which included weight-saving measures and handling according to Safety Car driver, Bruno Correia.

"I followed the building process of the Mini Pacesetter and there were some requests on the handling side of the car, which is basically the brakes, suspension and of course the 'look' of the car because it always goes in front of the field," says Correia.

The car produces 135kW of power and 280Nm of torque, which enables it to sprint from 0-62mph in just 6.7 seconds. It weighs just 1,230kg which is 130kg lighter than a standard Mini electric.

The drive system teams up with racing coilover suspension, which is three-way adjustable for rebound, compression, height, and camber. It also uses Race-spec suspension control arm mountings, a 10mm increase in track width, plus the four-piston brakes and wheels from the Mini John Cooper Works GP with the same Michelin Pilot Sport tyres used by the Formula E teams.

This performance is important as there can often be quite a few incidents in Formula E, with the Mini making four on-track appearances when it was introduced at the Rome E-Prix earlier this year due to rain and incidents.

"The Safety Car is a key element to the safety systems on every track, it's really important not only for the drivers but also for the people that work on the track that help us to run all this championship," says Correia.

Both the Mini Pacesetter and the i8 Roadster are on hand each weekend in case there is an issue with one, or they require a switch. Formula E also uses a local marshal from each race as the person who sits in the passenger seat with Correia, which helps them learn about the safety procedures.

"I know in Formula One they have two people who follow the championship," says Correia. "In Formula E we give the chance to a local marshal to sit with me in the car to enjoy a little bit and learn about the procedures that we do in the FIA. So, we always leave this message in the countries that we visit, I pass all my experience on to these guys so they can adapt in their countries."

AUTO+MEDICAL FEATURES

(4) **LIGHTS:** The Safety Car has three types of lights used to warn the drivers: the yellow lights are the main ones used to show the driver that they need to slow down and stay within a 10 cars length difference to the Safety Car. The green light is used to signal for a driver to overtake the Safety Car. For the first time in Formula E there is also red lights on the rear of the car, which are for a red flag situation and the race needs to be suspended.

(5) **TYRES:** The tyres at the front are the same Michelin Pilot Sport tyres used by the Formula E teams, which helps with the performance and balance on what can be narrow street tracks offering varying grip levels in both dry and wet conditions according to Correia. "It was a choice we made to make the car even more balanced and even with better performance. I'm using exactly the same profile of the front tyres used by the Formula E cars, which is really grippy and helps me in all kinds of weather situation if it's raining or dry."

(1) **MIRROR/HD CAMERA:** To help understand where each car is when it is behind, at the back there is a HD camera mounted which feeds a live image to the rear view-mirror.

(2) **INTERIOR:** A tablet uses WIFI, transponder, and GPS information from Race Control and displayed on the screen, so Correia knows exactly where a hazard or crash is or how the track conditions are before being dispatched by Race Control.

(3) **RACE CONTROL:** On the steering wheel there is push-to-talk paddle that is used by Correia to communicate directly with Race Control and the Formula E Race Director, Scot Elkins. "I'm an extra pair of eyes for the race director and the people in the race control, so it's important to be as quick as possible to remove the hazard and make sure the track is ready to go as soon as possible," says Correia. "It's important that while the Safety Car is on track, we can promote enough time to work on the circuit in the safest way."

THE ROAD BACK:

THEO POURCHAIRE

The Formula 2 racer discusses the injury he sustained on the opening lap of the Feature Race in Baku and his ongoing recovery.

During the opening lap of the Formula 2 Feature Race in Azerbaijan, Theo Pourchaire was racing closely with championship rivals Dan Ticktum and Marcus Armstrong. The trio went three-wide into turn three, when Armstrong on the outside turned into the corner and made contact with Pourchaire. This caused the Frenchmans car to jump into the air briefly and hit Ticktum who was on the inside of the corner, before coming to a stop in the escape road.

Pourchaire managed to make it back to the pits, but once he was out of the car he was seen holding his wrist while speaking to medical staff. It subsequently emerged that the contact between the three cars had broken the Radius in his left arm, and that he was taken to hospital for treatment. *AUTO+ Medical* speaks to Pouchaire about the injury, how he prepared for the next round in Silverstone, and his ongoing recovery.

AUTO+ Medical: **How did the injury Happen?**
Theo Pourchaire: It was the Radius in my left arm that was broken. It was a very small thing because it was just between the wrist and the Radius and it was really, really painful and I couldn't move the wrist. It happened in Race 3 in Baku, we were three-wide and when we touched each other. We don't have power steering in Formula 2, so the steering wheel is really heavy and it's the same if you're at 300kph or touching each other at 120kph. When we touched the car just jumped a bit into the air and the steering wheel turned really heavy to the right. Then when the car touched the ground again, it snapped back to the left, and that's how I broke my Radius.

A+M: **What was it like when you got out of the car?**
TP: Just after the contact I felt another pain, but I was not turning with the steering wheel so my arm was completely straight which is why I couldn't feel anything. But as soon as I went into reverse gear and started to go back to the pit lane to stop the car, it was impossible to turn and even touch the steering wheel, so I continued to go back to the pits because it was the best thing to do as it started to get really, really painful. Once I was out of the car it was impossible even to hold something because I couldn't move my wrist.

A+M: **Did you go to the hospital after that?**
TP: Yes, I went to the medical centre in the track where they gave me something to ease the pain

AUTO+MEDICAL FEATURES

because at that moment I could feel my heartbeat in my arm. I was almost collapsing because it was really painful. We did some x-rays and they saw the Radius was broken, and they told me to go to the hospital because it was the best way to immobilise the arm. Later at home I did some treatment to get ready for Silverstone, which was the Tecar Therapy, and this was the best thing to do. I had no surgery because the bone was just a little bit broken and was still straight and didn't move a lot. I did the Tecar Therapy for five weeks almost every day and this helped me a lot to go back and to move the blood in the arm. It also helped to grow the new bone and beside that I also did a lot of cold water on it, Green Argile Clay on the Radius to regenerate the arm faster.

A+M: Is this what you were seen doing on your social channels at Silverstone following the races?
TP: That is the Tecar Therapy, I had this with me in Silverstone because it was still painful and difficult to drive, and it was important to have this with me to do that every evening. This machine is very interesting because I discovered that we could use Tecar Therapy not only for broken bones but also at the end of the day if you have some pain after driving or if you have some jet lag you can use it. It's really impressive and it worked on me very well.

A+M: Did you do any sim work before the Silverstone round?
TP: Two weeks before the race in Silverstone I was not sure whether I would be able to drive. I did one day of the sim with the team, but it was really, really difficult. This was a week before the race and it was painful, I was not driving with the real force of the steering wheel because I wanted to be back at Silverstone and not risk

Photo Credit: Theo Pourchaire Instagram

Pourchaire was seen clutching his wrist after the accident

> **"TWO WEEKS BEFORE SILVERSTONE I WASN'T SURE IF I WAS GOING TO DRIVE"**

another injury in the sim, so it was important to do something just to get the confidence back because today I'm still a bit worried about doing push ups in the gym or things that are difficult on the arm, and in my mind I don't want to make it worse or create something bad. It was also important mentally to do something.

A+M: Did you make any modifications to the car when you got back into it?
TP: I put some straps on my forearm to maintain the wrist position and to not have too much movement, to be a bit more comfortable mentally and to help a bit physically because it was still painful. Apart from that it was exactly the same car as was raced in Baku, I struggled a bit physically because for five weeks I was immobilised and I couldn't do a lot of sports or gym, I was doing just a bit of sports for the right arm and the neck but with the left arm it was almost impossible. Apart from a bit of straps on my hand, the car was the same.

A+M: With the races being separated by months rather weeks, has that helped your recovery?
TP: Yes it helped me for sure because we had five or six weeks between Baku and Silverstone, and it was already really, really tight in terms of timing for me to race at Silverstone but I did it and it helped me have those few weeks. Now we have eight weeks before Monza, so this is perfect, and I can work again and be back 100 per-cent for this race to get more movement in the arm. I'm still doing some exercises to have the arm back to normal as before.

A+M: What advice do you have for drivers who suffer similar injuries?
TP: It's really difficult mentally, you have to never give up and give everything because for me I had only one thing in my head: to race in Silverstone. I did it, but takes a lot of hard work and dedication for six weeks I was every day at the doctors doing a lot of things on my arm, putting cold water, Green Argile, what I was eating was different too a lot of milk, Vitamin D, Vitamin K, so I did everything to be back at Silverstone.

AUTO+MEDICAL FEATURES

SCIENTIFIC ARTICLE:

CUSTOMIZING FEMALE RACING DRIVERS' SEAT FIT CAN IMPROVE THEIR PERFORMANCE

Simon M Rosalie[1, 2] and Simone Rosalie
[1]Curtin School of Allied Health, Curtin University, Australia
[2]Department of Industrial Engineering, University of Florence, Italy

AUTO+MEDICAL SCIENCE

AUTO+MEDICAL SCIENCE

Abstract

To attain peak performance, a racing driver needs to be stable in their seat. A stable driving position is thought to increase sensitivity to visual and vestibular information thereby enabling more skillful vehicle control. Optimizing seat fit to enhance stability could profoundly improve steering behavior of the driver and thus their performance. Here we report how using an electromyography (EMG)-based methodology for optimizing seat fit improved the performance of amateur women racing drivers. We measured the neck, shoulder, and trunk muscle activities of four women racing at amateur level as well as the angle of their neck and lower back with respect to vertical and their performance in terms of lap time. The seat insert decreased the neck and lower back angles of three of the four drivers. The lap times of these three drivers improved. Improved lap times were associated with changes in neck muscle activity consistent with a decrease in forward head position and reduced neck lateral flexion (head tilt). Improved lap times were also associated with changes in shoulder and trunk muscle activities consistent with adopting a right arm dominant steering action. Using electromyography to guide optimization of seat fit can have profound effects on neuromuscular processes underlying steering behavior of the driver, particularly the activity of neck muscles used to orient the head. These effects can translate to improved performance.

Keywords

Motor sport, seat fit, steering behavior, electromyography, EMG, driving position

Introduction

An optimal driving position can enhance the performance of a racing driver. Stability is critical. A stable position is thought to increase sensitivity to visual and vestibular information compared to an unstable position, thereby promoting more skillful vehicle control during cornering (Treffner et al., 2002). Training drivers to improve their stability by bracing is effective in improving vehicle control and lateral acceleration (Petersen et al., 2008). This translates to better cornering speed. However, gains in driver performance beyond those achievable through training could be generated by modifying the seat to optimize driving position.

Motor sport is unique. It is the only sport in which men and women compete against each other, ostensibly without a sex bias enshrined within the regulations (except for FIA W series). However, the reality of a sex neutral competition is far from the truth. Currently all drivers competing in the FIA Formula 1, FIA Formula 2 and FIA Formula 3 World Championships are male (F1 Drivers 2021 -Hamilton, Verstappen, Vettel and more, retrieved April 3, 2021; Teams & Drivers -Formula 2, retrieved April 3, 2021; Teams & Drivers - Formula 3, retrieved April 3, 2021). The male bias in the design of racing seats, restraints, and impact testing (Troxel, 2008), in racing regulations and crash testing (Welsh & Lenard, 2001), and in racing apparel (Tian et al., 2020) is likely to disadvantage female drivers in terms of performance. This male bias is particularly important in closed-cockpit racing because the design of many closed-cockpit racing cars is heavily influenced by the design of their road-based counterparts. The male bias evident in the design of road cars has long been recognized to result in women being disproportionately injured in motor vehicle accidents (Bose et al., 2011; Marshall et al., 2010; Ryan et al., 2020; Welsh & Lenard, 2001). This is thought to be due to a male bias in the design of seats and restraints (Bose et al., 2011) combined with differences in driving position (Ye et al., 2015). Consequently, women competing in motor sport are likely to be disadvantaged in terms of both performance and safety compared to their male counterparts due to key elements of vehicle design

“TRAINING DRIVERS TO IMPROVE THEIR STABILITY BY BRACING IS EFFECTIVE”

including seat design and driving position.

Recently, we reported a case study describing how we improved the performance of an experienced amateur female racing driver by using an electromyography (EMG)-based methodology to optimize her driving position (Rosalie & Malone, 2019b). The methodology that we used was first developed by Rosalie

(2015) and has since been replicated by Rosalie and Malone (2018a, 2018b, 2019a). EMG optimization of seat fit resulted in a 2.18s improvement in the average lap time of the driver over a ten-lap stint. Improved lap times were associated with changes in neck muscle activity and head-neck angle of the driver that were consistent with correction of an overly forward head position. Previous work has shown that a forward head position increases lateral flexion in the direction of rotation (head tilt) resulting in increased tonic activity of the sternocleidomastoid, a pair of muscles that connect the sternum, clavicle, and mastoid process of the temporal bone and serve to turn, tilt, and nod the head (Kim, 2015). This increase in tonic activity of the sternocleidomastoid is probably due to changes in proprioceptive input from muscle spindle fibers (Pettorossi & Schieppati, 2014). Lateral flexion in the direction of rotation has the potential to cause the driver to “understeer” through corners by deviating steering trajectory away from the direction of rotation. This is because proprioceptive input from the sternocleidomastoid informs perception of rotation in the direction opposite to the anatomical location of the muscle (Bove et al., 2001; Land & Tatler, 2001; Pettorossi & Schieppati, 2014). So, activating the right sternocleidomastoid to laterally flex the head to the right during a right-hand turn will deviate perceived head angle to the left thus affecting accurate perception of steering angle. Consequently, using EMG to detect and correct coordination patterns that increase the risk of driver error caused by misperception of head angle has great potential to improve driver performance. The seat clearly influences these coordination patterns. Therefore, using EMG to guide optimization of the seat warrants further study.

This study is part of a larger investigation examining steering behavior in various categories of motor sport. In our first study we focused on drivers of open-cockpit formula cars (Rosalie & Malone, 2019a). In this, our second study, we focused on drivers of closed-cockpit cars. In upcoming studies, we will focus on motorcycle riders. The aims of the overall investigation were to investigate whether the increased attentional demands of intentionally following another car caused drivers to modify their coordination pattern for steering compared to driving on a clear track. We expected that muscle activation patterns of drivers of all three vehicle types would be affected by intentional following, but that the specific changes would depend on vehicle type (symmetrical vs. asymmetrical, motorcycle vs. car). Our hypotheses for the overall investigation

AUTO+MEDICAL SCIENCE

were as follows: first, that intentionally following another car would result in the allocation of attention to a narrower visual search strategy resulting in a reduction of head movement and consequently a decrease in neck muscle activity; second, that a decrease in head movement would lead to a change in steering movements and thus shoulder muscle activity; third, that a change in upper limb movement would lead to a change in the activation patterns of trunk muscles.

Here we report differences in performance, muscle activity, and spinal angles for a group of female drivers who completed the task of driving on a clear track in closed cockpit cars with and without a customized seat insert. The purpose of the customized insert was to ensure that the drivers were safely harnessed to the seat, had unimpeded vision, and could comfortably operate the controls. It is standard practice to adjust the seating position of the driver in the cockpit to optimize visibility, fit of safety harnesses and position relative to the steering wheel, gear lever and peddles for safety purposes. However, this process is rarely, if ever, completed according to a validated scientific method.

Methods

Participants

The Curtin University Human Research Ethics Committee granted approval for a project using a naturalistic observational design to investigate muscle activity underlying steering behavior during practice, qualifying, and racing sessions when intentionally following another vehicle compared to driving unhindered (HR191/2014). This study focuses on closed-cockpit racing drivers. Four women gave written informed consent to participate. Driver 1 was 69 years old with 5 years' experience and the highest level of competition of club level. Driver 2 was 21 years old with 6 months experience and the highest level of competition of club level. Driver 3 was 37 years old with 18 years' experience and the highest level of competition of national level. Driver 4 was 51 years old with 33 years' experience and the highest level of competition of international level.

> **"AN OPTIMAL DRIVING POSITION CAN INCREASE CORNERING PERFORMANCE"**

Location and equipment

We collected data over two weeks at a private racetrack. The 4 km (2.5 mile) long track was operated in a clockwise configuration consisting of eleven right-hand corners and eight left-hand corners. Three drivers drove naturally aspirated Porsche 944s modified to SCCA racing specifications by Raptor Motorsports (AZ, USA). The fourth driver drove a privately owned, race prepared Honda S2000.

We measured the activation patterns of seven muscles: sternocleidomastoid, cervical erector spinae, anterior deltoid, pectoralis major, lumbar erector spinae, rectus abdominis, and transversus abdominis, bilaterally using surface electromyography (EMG) sensors with integrated inertial measurement units (IMU)

(Delsys, Trigno IM, Boston, MA, USA). Data from each sensor were transmitted wirelessly to a manufacturer supplied data logger (Delsys, TPM, Boston, MA, USA) which synchronously recorded the data from the 14-sensor array. We positioned the measuring electrodes according to the recommendation of the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) Project for the placement of measuring electrodes (Hermens et al., 1999) except for the following: The electrode measuring muscle activity of pectoralis major medially was placed along the line of the sternal portion to capture its activity during downward rotation of the steering wheel (Król et al., 2007; Pick & Cole, 2006); the electrodes measuring the activities of transversus abdominis and rectus abdominis were placed according to the recommendations of Marshall and Murphy (Marshall & Murphy, 2003).

The drivers were instructed not to remove the electrodes until they had completed the testing protocol. The electromyographic data were recorded in millivolts at a rate of 1111Hz, accelerometry and gyroscopic data at 148 Hz, and magnetometry at 74 Hz. The TPM also incorporated a tri-axial accelerometer which sampled at 148Hz. We used a 10 Hz global positioning system (GPS) with an integrated 100Hz inertial measurement unit (Catapult Optimeye S5, Catapult Sports, Docklands, Australia) to measure track position and lap time. We co-mounted the Catapult S5 and Delsys TPM in the cockpit of each test vehicle and time synchronized them using a sequence of taps which were recorded by the accelerometers in each unit. The same GPS unit was used for every test which allowed an accurate determination of how muscle activity corresponded to where the drivers were on the track and how many laps they had completed.

Experimental Design and Procedures

In the days preceding our data collection, all four drivers participated in an unrelated study carried out by a separate research team on the same track using the same vehicles. The drivers were therefore likely to have acclimatized to both the track and their vehicles. We decided that it was necessary to optimize the seating position of the drivers prior to commencing the experiment proper for two reasons. The first reason was safety. An appropriate seating position reduces the risk spinal injury in the event of a crash (Trammell & Flint, 2012) . We were not confident that the generic seats installed in the cars were appropriate for the drivers. The second reason was experimental control. The drivers who participated in our previous study of steering behavior in closed-cockpit formula cars (Rosalie & Malone, 2019a) all used custom fitted racing seats.

As the methodology of this study was identical to our previous study, an equivalently stable driving position was critical to reliability.

The evening before they were scheduled to drive, we adjusted the drivers' seat, pedals, steering wheel, and racing harness until they were satisfied with their driving position. In addition, a customized seat insert was molded for each driver using an SFI approved kit (BSCI Energy Impact Systems, Mooresville, NC, USA). The insert was fitted after the driver made her initial attempt at the solo task if she reported being dissatisfied with her driving position. Molding the insert involved filling a large bag, placed between the driver and her seat, with self-expanding poly-urethane foam that conforms to the position of the driver before hardening. We visually inspected the positions of Driver 1, Driver 2, and Driver 3 during the molding process to ensure that it corresponded to the position used for the case study driver (Rosalie & Malone, 2019b). Due to time constraints, the seat insert for Driver 4 was molded without our oversight.

Over the following days each driver completed her initial attempt at the solo task which consisted of completing a ten lap "qualifying session" on a clear track. Each driver commenced in the pits where she was strapped into her car. After activating and synchronizing the TPM and Catapult data loggers, each driver was asked to remain still for 30 seconds in her normal driving posture to measure baseline muscle activity and position. The driver then started her car and exited the pits.

The task was separated into three parts. First, the driver completed two warm-up laps to heat the tires and acclimatize to track conditions. After the warm-up laps, the driver immediately commenced a ten-lap stint driving as fast as safely possible. She then drove one final cooldown lap to complete the test before returning to the pits. To orient the drivers to the racing context, a green flag was waved to start the qualifying stint and a checkered flag to end it. We met each driver as she re-entered the pits to ask for immediate feedback on whether she felt secure and comfortable in the seat. None of the drivers reported being satisfied with her seating position. Therefore, a mechanic fitted the seat insert while the driver rested and rehydrated in an air-conditioned lounge. After a minimum of two hours, the driver reattempted the solo task.

Data Processing

The subset of data presented here describes the effect that optimizing driving position had on driver performance and muscle activation patterns. We processed the data using the same procedure used for the case study (Rosalie & Malone, 2019b). From the GPS unit we extracted lap time and total elapsed time. From the cervical (C7) and lumbar (L1) EMG/IMU sensors we extracted the angles of inclination of the lumbar and cervical spine with respect to gravity during the period that the driver was sitting still before commencing the solo tasks. For these data, we computed average angles over a 20s period. A negative change in angle corresponded to a more vertical position. We used the data from the rate gyroscope to confirm that the driver was still during the measurement window.

We analyzed the time-dependent median frequency of the EMG power spectrum to determine an index of muscle activity (Phinyomark et al., 2012). We imported the GPS data into Delsys EMGworks (Delsys, Boston, MA, USA) and used this data to create a subset of the raw electromyographic data corresponding to the 10 qualifying laps. We bandpass filtered this data using a 4th order Butterworth filter with corner frequencies of 20Hz and 500Hz. Then we used a short-time Fourier transform with a window length of 0.125s and a window overlap of 0.0625s to calculate the median frequency of the EMG power spectrum of each muscle. The median frequency data were normalized to a percentage of the maximum median frequency per muscle per test.

Statistical Analysis

We used two level mixed effects growth models with maximum likelihood estimation to analyze within-driver and between-driver change in both lap time and normalized median frequency

(NMF). We chose to use individual growth curve (IGC) models instead of the more traditional repeated measures ANOVA for four reasons. First, our analysis is longitudinal; that is, it examines intra-individual change over time. Therefore, it is unlikely that each observation is truly independent. This violates the assumption of independence of observations. Second, our design is unbalanced (unequal sample sizes). Using ANOVA in these circumstances increases the risk of Type I error compared to IGC models. Third, IGC models permit the examination of both individual and group level (aggregated) curves. In contrast, repeated measures ANOVA only allows for group level analysis. Fourth, the effects of both invariant and time-variant predictors can be added to IGC models to examine associations between predictors and change in the dependent variables over time. Repeated measures ANOVA lacks such flexibility. (See Shek and Ma [2011] and Singmann and Kellen [2019] for more detailed information on the advantages of IGC models for the analysis of time series data).

Our Level 1 IGC model for lap time examined within-driver change across 10 matched pairs of laps per driver. Hence, lap times—and not drivers—are the unit of observation (what is being measured) for the lap time analysis. Similarly, our Level 1 model for the muscle activity data examined within-driver change in normalized median frequency across matched pairs of measures taken every 0.0625s for the duration of the session. The Level 2 models examined between-driver change in lap time and NMF for the four drivers across the two sessions. Hence, total sample size for the Level 2 lap time model was 75 laps (Driver 3 missed 5 laps in the session driven without the insert). Total sample size for the Level 2 NMF models was 147044 samples per muscle.

Our analytic strategy involved progressively testing unconditional linear, quadratic, and cubic trends for model fit. For the muscle activity data, this was done by grouping the seven muscles sampled into three distinct anatomical regions: the neck, the shoulder, and the trunk. Model fit was determined based on the results of Chi-square likelihood ratio tests. A quadratic trend was tested only if the linear trend was statistically significant. Likewise, a cubic trend was tested only if the linear and quadratic trends were statistically significant. This approach is consistent with the recommendations of Singer and Willet (Singer & Willett, 2003) and Field (Field, 2013) for using growth models to examine rates of change over time and identical to the approach in previous studies of steering behavior of race car drivers (Rosalie & Malone, 2018a, 2018b, 2019a, 2019b).

Time-invariant predictors were added to the Level 2 models with the best fit to investigate whether driving position (i.e., Generic and Custom) was a predictor of lap time and NMF (i.e., a fixed effect). In addition, individual differences were examined by progressively specifying random effects for the intercept, slope, and both the intercept and the slope using a heterogenous first order autoregressive or variance components covariance structure.

Again, model fit was tested using Chi-square likelihood ratio tests. For the lap time data, the intercept corresponds to lap time in the first lap and the slope to how lap time changes over the ten laps. For the NMF data, we have reported only the slope of the fitted growth curve which corresponds to fatigue resulting from muscle activity (Cifrek et al., 2000; Roy & De Luca, 1989). Muscle use, which results in fatigue, causes a downward shift in NMF which is represented by a negative slope (Cifrek et al., 2000; Phinyomark et al., 2012; Roy & De Luca, 1989). However, the model still retains the y-intercept to control for differences in initial contractile level (that is, unmodified by muscle use) between conditions (Cifrek et al., 2000; Roy & De Luca, 1989).

Results

Lap Time and Driving Position

Each driver drove ten laps in a generic seat followed by ten laps in a customized seat except for Driver 3, who completed only five laps in the generic seat because she was dissatisfied with her driving position. Drivers 1, 2, and 3, who all improved their lap time, drove a combined total of 55 laps (n = 55). Driver 4, who did not improve her lap time, drove a combined total of 20 laps (n = 20). The results of the lap time analysis are reported in Table 1.

Lap times neither changed significantly across the ten-lap session ($p = 0.539$), nor varied significantly across drivers (pvar(u0j) = 0.21, pvar(u1j) = 0.97). Drivers 1, 2 and 3 improved their lap times by an average 4.60s (SE = 1.4s) with the seat insert fitted ($p = 0.003$). In contrast, Driver 4 was 0.35 seconds slower with the seat insert; however, the difference was not significant ($p = 0.72$). The insert for Driver 4 was molded without our oversight. Given the difference in performance outcome for Drivers 1, 2 and 3 compared to Driver 4, a grouping factor (No Improvement vs. Improved) was added for subsequent analyses. Cervical and lumbar angles from the Improved and No Improvement Groups are shown in Table 2.

Neck Muscle Activity

The results of the analyses of neck muscle activity are reported in Table 3 (Appendix A) and the fitted conditional models are shown in Figure 1. A significant Group (No Improvement vs. Improved) X Condition (Generic vs. Custom) interaction, F(1, 587814) = 1560.56, $p < 0.001$ suggested that the effect of the seat insert on neck muscle activity differed between groups. In the No Improvement group, the seat insert was associated with significantly decreased activity of left sternocleidomastoid ($\beta = 14.70$, $p < 0.001$) and left cervical erector spinae ($\beta = 29.31$, $p < 0.001$) and significantly increased activity of right sternocleidomastoid ($\beta = -22.40$, $p < 0.001$). The effect sizes for right sternocleidomastoid ($\beta = -22.40$, $p < 0.001$) and left cervical erector spinae compared to left sternocleidomastoid suggest an increase in right lateral flexion and a decrease in right rotation in right hand corners.

Table 1. Lap time in seconds for each driver with respect to driving position

Driver	1		2		3		4	
Lap	Generic	Custom	Generic	Custom	Generic	Custom	Generic	Custom
1	134.09	138.48	125.46	126.74	143.76	134.40	120.91	119.90
2	135.58	136.61	124.38	127.31	138.50	133.20	121.43	120.98
3	146.00	138.51	124.30	127.84	135.70	135.00	120.29	126.20
4	142.06	137.83	124.58	127.13	136.20	134.90	120.64	123.32
5	141.23	133.63	156.82	126.34	154.40	136.20	122.61	120.58
6	138.57	134.88	126.06	124.96		131.60	120.29	120.10
7	146.07	134.99	124.34	125.70		132.50	122.23	120.58
8	141.70	135.66	125.23	125.08		133.30	123.53	127.69
9	143.61	135.62	124.99	125.20		131.30	121.06	118.64
10	141.80	138.51	126.44	125.77		129.30	121.60	120.09
Mean	141.07	136.47	128.26	126.21	141.71	133.17	121.46	121.81
SD	3.98	1.78	10.06	1.02	7.78	2.07	1.06	2.97
Performance Outcome	Improved		Improved		Improved		No Improvement	

Table 2. Cervical and lumbar angles grouped by the effect.

	Improved		No Improvement	
	Generic	Custom	Generic	Custom
Cervical angle				
Mean	25.02	18.71	26.50	26.37
SD	7.48	6.04	1.38	0.90
Lumbar angle				
Mean	29.24	22.46	28.30	27.06
SD	5.84	8.82	0.65	0.15

Note: Angles are expressed in terms of degrees from vertical.

In contrast, in the Improved group, the seat insert was associated with significantly decreased activity of left sternocleidomastoid ($\beta = 9.65$, $p < 0.001$), right sternocleidomastoid ($\beta = 10.66$, $p < 0.001$) and right cervical erector spinae ($\beta = 13.95$, $p < 0.001$) and increased activity of left cervical erector spinae ($\beta = -18.11$, $p < 0.001$). The effect sizes suggest an overall decrease in neck muscle use.

Results for the random effects test for individual differences in the Improved group revealed that neither intercepts (initial contractile level) nor slopes (rates of fatigue) varied between drivers for any of the four neck muscles. However, intercepts and slopes for left cervical erector spinae negatively and significantly covaried, cov (u0j , u1j) = -0.82, $p < 0.001$ indicating that as initial contractile level increased rate of fatigue also increased. In contrast, intercepts, and slopes for right cervical erector spinae positively and significantly covaried, cov (u0j , u1j) = 0.67, $p = 0.01$ indicating that as initial contractile level increased so did the rate of change in activity.

Shoulder Muscle Activity

The results of the analyses of shoulder muscle activity are reported in Table 4 (Appendix B) and the fitted conditional models are shown in Figure 2. A significant Group (No Improvement vs. Improved) X Condition (Generic vs. Custom) interaction, F(1, 588166.79) = 651.08, $p < 0.001$, suggests that the effect of the seat insert on shoulder muscle activity differed between groups. In the No Improvement group, the seat insert was associated with significantly increased activity of left anterior deltoid ($\beta = -11.08$, $p = 0.001$) and significantly decreased activities of right pectoralis major ($\beta = 19.09$, $p < 0.001$) and right anterior deltoid ($\beta = 13.49$, $p < 0.001$). The effect sizes for left anterior deltoid and right pectoralis major suggest a shift in the production of torque for right turns towards the left anterior deltoid. However, the effect sizes for right anterior deltoid and left pectoralis major ($\beta = 2.94$, $p = 0.15$) do not suggest a similar change for left hand turns largely because the latter is not significantly different.

In the Improved group, the seat insert was associated with significantly increased activity of right anterior deltoid (β = -19.05, $p < 0.001$) and right pectoralis major (β = -8.74, $p < 0.001$) which suggest that the production of steering torque shifted towards the right upper limb for both left and right turns.

Results for the random effects test for individual differences in the Improved group revealed that neither intercepts (initial contractile level) nor slopes (rates of fatigue) varied between drivers for any of the four muscles of the shoulder girdle.

Trunk Muscle Activity

The results of analyses of the trunk muscle activity are reported in Table 5 (Appendix C) and the fitted conditional models are shown in Figure 3. A significant Group (No Improvement vs. Improved) X Condition (Generic vs. Custom) interaction, $F(1, 882227.60) = 876.19$, $p < 0.001$, suggested that the effect of the seat insert on trunk muscle activity likewise differed between groups. In the No improvement group, the seat insert was associated with significantly increased activity of right lumbar erector spinae (β = -11.27, $p = 0.05$) and significantly decreased activities of left rectus abdominis (β = 47.29, $p < 0.001$), left transversus abdominis (β = 22.90, $p < 0.001$) and right transversus abdominis (β = 14.09, $p = 0.008$).

In the Improved group, the seat insert was associated with significant decreases in the activities of right lumbar erector spinae (β = 6.98, $p = 0.01$), right rectus abdominis (β = 12.33, $p < 0.001$). and right transversus abdominis (β = 11.58, $p < 0.001$) and a significant increase in the activities of left transversus abdominis (β = -20.45, ps < 0.001).

Results for the random effects test for individual differences in the Improved group revealed that neither intercepts (initial contractile level) nor slopes (rates of fatigue) varied between drivers for any of the six trunk muscles.

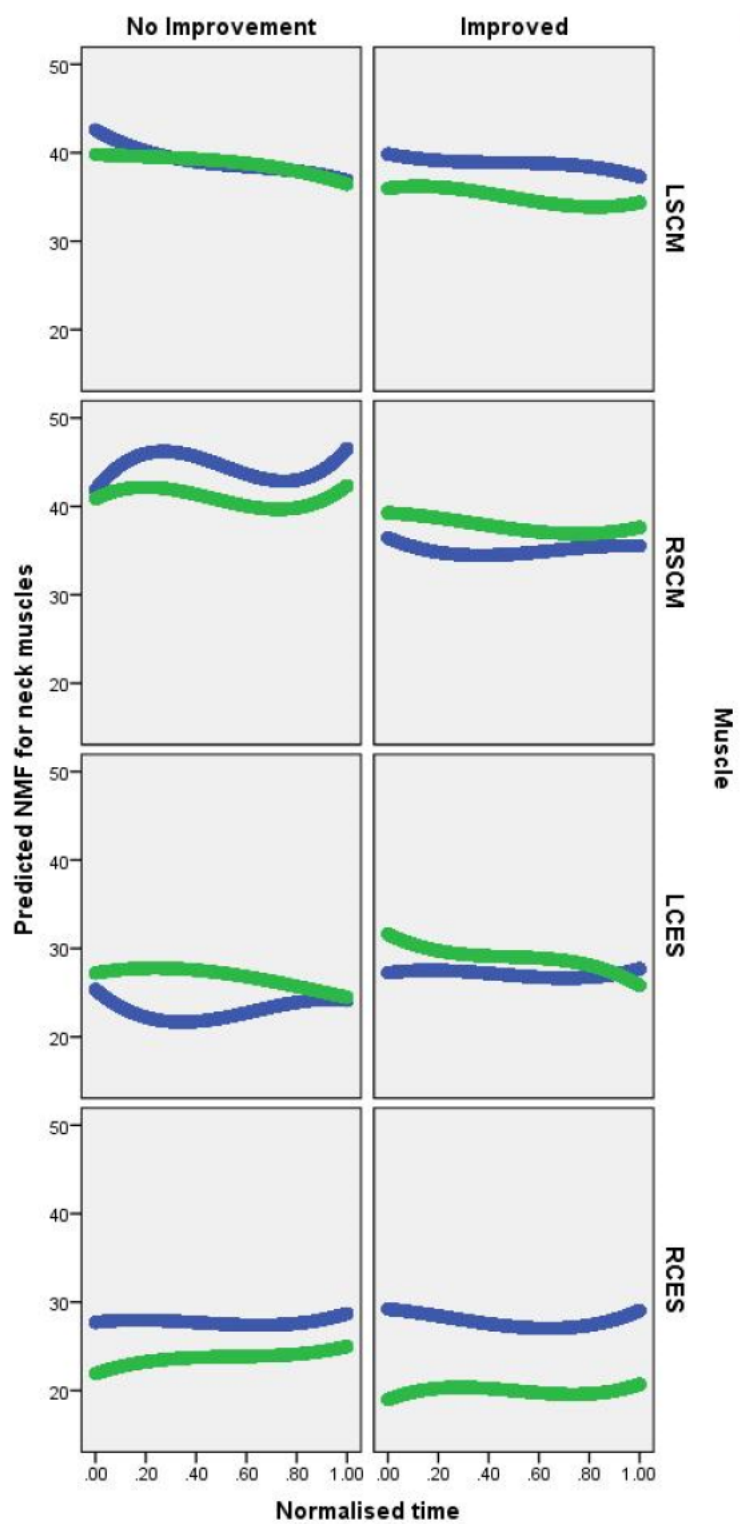


Figure 1. Neck muscle activity: fitted conditional growth curves showing the effect of driving position on normalized median frequency of left sternocleido-mastoid (LSCM), right sternocleidomastoid (RSCM), left cervical erector spinae (LCES) and right cervical erector spinae (RCES). The blue curves correspond to Generic and the green curves to Custom.

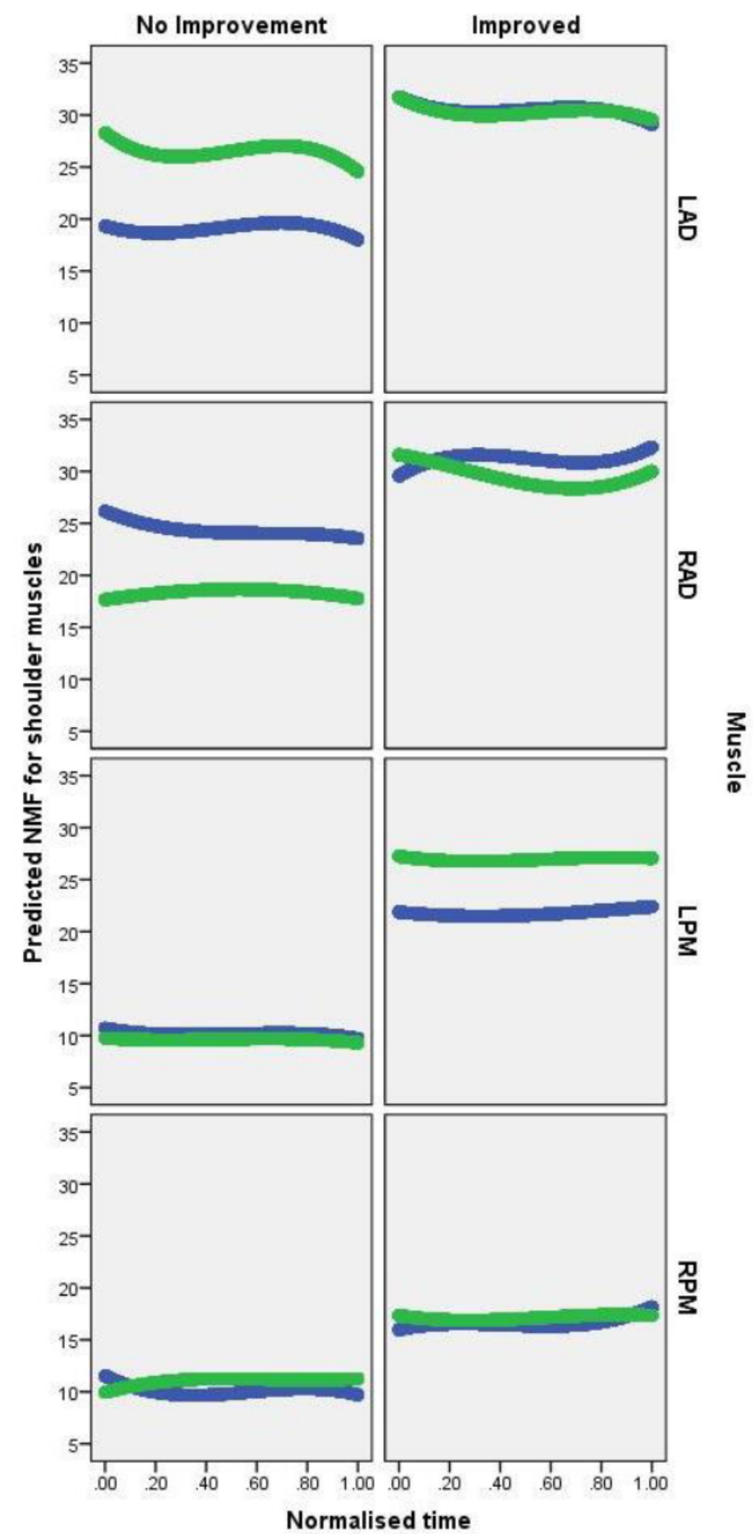


Figure 2. Shoulder muscle activity: fitted conditional growth curves showing the effect of driving position on normalized median frequency of left anterior deltoid (LAD), right anterior deltoid (RAD), left pectoralis major (LPM) and right pectoralis major (RPM). The blue curves correspond to Generic and the green curves to Custom.

AUTO+MEDICAL SCIENCE

Discussion

Based on the existing literature, there are two potential explanations for why the seat insert improved the performance of three drivers. One, improved lap times were only recorded for drivers whose cervical angle was decreased numerically by the seat insert. Presumably, this reduction in cervical angle resulted in the bilateral decrease in sternocleidomastoid activity. Previous research has shown that when seated in a reclined position, a bilateral decrease in the activity of sternocleidomastoid is consistent with a decrease in neck flexion (Smulders et al., 2019). However, the decrease that we measured in sternocleidomastoid activity was asymmetrical and accompanied by an asymmetrical change in pattern of the drivers. The larger effect size for right sternocleidomastoid and the numerical increase in activation of right cervical erector spinae suggests that right lateral flexion decreased (Moroney et al., 1988).

In contrast, lap times did not improve for the driver whose seat insert did not alter cervical angle. The sternocleidomastoid activity of this driver increased on the right and decreased on the left. Most of the corners on the test track were right-hand corners. So, a forward head position in this test is likely to increase lateral flexion to the right resulting in increased activity of right sternocleidomastoid (Kim, 2015). The resulting misalignment in visual and proprioceptive information is likely to cause the driver to 'undershoot' right hand corners by deviating her perceived head angle to the left (Bove et al., 2001; Land & Tatler, 2001; Pettorossi & Schieppati, 2014).

An alternative explanation is that the seat insert could have increased the stability of the drivers who improved their lap times. However, the trunk muscle activities of the drivers who improved changed asymmetrically, which is not consistent with this explanation. Instead, the activity of all three muscles measured on the right side of the trunk decreased

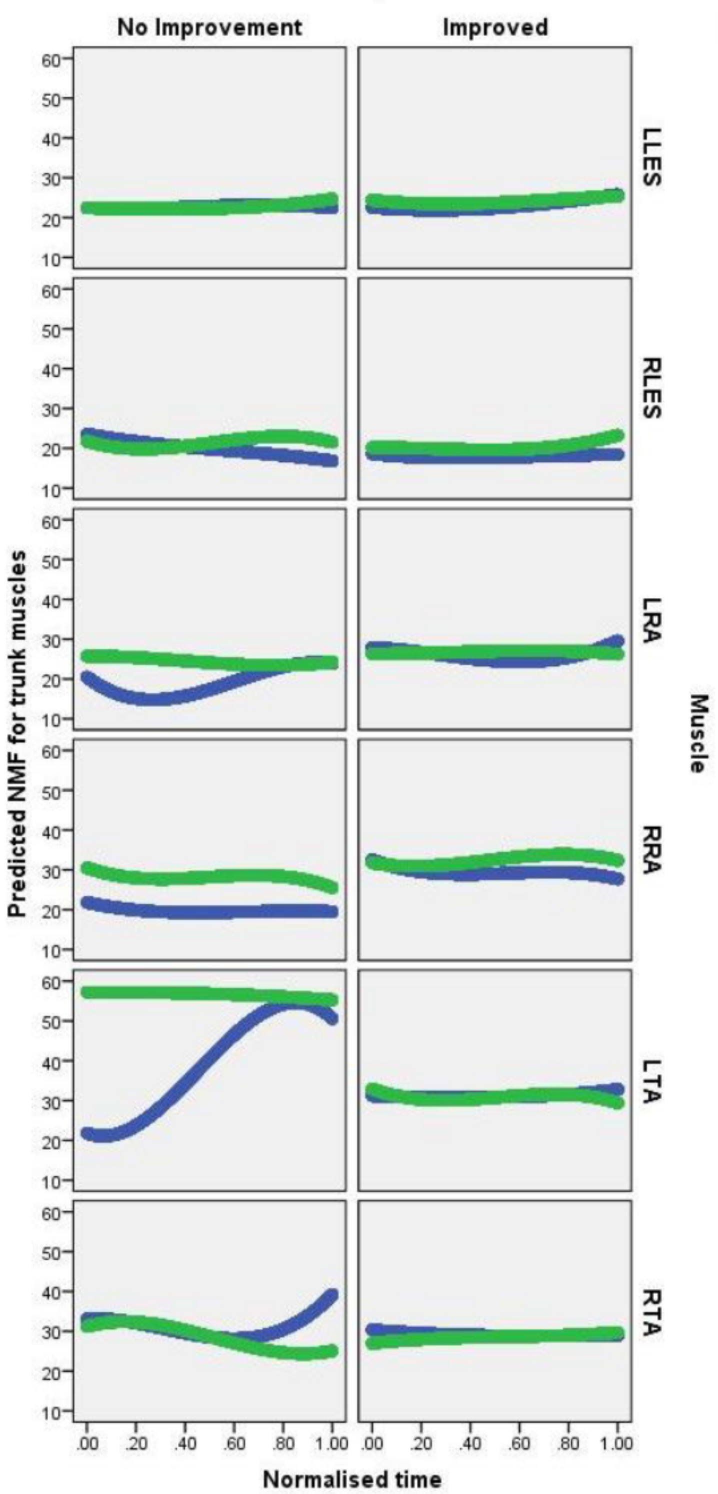


Figure 3. Trunk muscle activity: fitted conditional growth curves showing the effect of driving position on normalized median frequency (NMF) of left lumbar erector spinae (LLES), right lumbar erector spinae (RLES), left rectus abdominis (LRA), right rectus abdominis (RRA), left transversus abdominis (LTA) and right transversus abdominis (RTA). The blue curves correspond to Generic and the green curves to Custom.

while that of left transversus abdominis increased. This probably reflects adoption of a more right arm dominant steering pattern with increased activity of right anterior deltoid and right pectoralis major. Right anterior deltoid produces positive tangential steering torque for left-hand corners and right pectoralis major produces negative tangential steering torque for right-hand corners (Pick & Cole, 2006). Trunk extensors are thought to act to oppose torque produced by the opposite upper limb while trunk flexors may act non-directionally (Hodges et al., 2000; Hodges et al., 1999; Marshall & Murphy, 2003).

The shoulder and trunk muscle activation patterns of the driver who did not improve her lap times provides further evidence that a shift in the production of steering torque is responsible for a change in trunk muscle activation. In this driver, a decrease in the activity of muscles of the right shoulder girdle and an increase in the activity of left anterior deltoid suggests that the production of steering torque, at least for right hand corners, shifted towards the production of positive tangential torque by the left upper limb. Presumably, the activities of right lumbar erector spinae and right transversus abdominis increased to balance this torque. Notably, the effect of the seat insert on the shoulder and trunk muscle activities of this driver are almost a mirror image of the changes measured in the drivers who improved their lap times. One possible explanation is that drivers who improved their laps time were in a different position relative to the steering wheel and the gear lever. This difference in position favored different strategies to achieve the same goals of steering and changing gear thereby modifying the activation patterns of shoulder and trunk muscles. The phenomenon whereby different movement strategies are used to achieve the same goal is known as motor equivalence.

This study is the fifth replication of Rosalie's (2015) methodology published in the peer reviewed scientific literature. Two studies, this and Rosalie and Malone (2019b), have demonstrated that driver performance improves when neck lateral flexion (head tilt during cornering) is decreased. The three remaining studies all showed that neck lateral flexion increases when the demands placed on the attention of the driver are increased, either by intentionally following another car (Rosalie & Malone, 2019a) or by an unfamiliar visual distraction (Rosalie & Malone, 2018a, 2018b).

We have also used this methodology in a "clinical" setting. By measuring how the neuromuscular system of the driver responds to various challenges on track and combining these measurements with vehicle telemetry, onboard video, and accurate GPS, it is possible to predict track locations and race conditions that will that cause the driver to make an error (leading to an accident), prescribe remedial training the treat the underlying cause, and return to the driver to the track with improved performance (Rosalie, 2020).

The common finding in both research and clinician settings is that excess neck lateral flexion reduces the accuracy of visual perception in race drivers leading to a decline in performance. The reason why this occurs is complicated. Unlike road drivers who use eye movements to navigate bends (Land & Lee, 1994), race drivers navigate via head rotation (Land & Tatler, 2001). Fans of motorsport will be familiar with drivers tilting their heads (neck lateral flexion) into a corner, particularly in high G-Force motorsports such as F1. While this phenomenon is typically attributed to alignment of the head with centripetal (cornering) forces, head tilt is poorly correlated with centripetal force (Zikovitz & Harris, 1999). Instead, it is thought that drivers tilt into a corner to maintain a stable visual reference for the curvature of the road (Zikovitz & Harris, 1999). This automated response, known as the optokinetic cervical reflex, has also been observed in pilots of high performance aircraft when turning into and out of a bank (Coakwell et al., 2004).

There are several reasons why reflexive lateral flexion is not considered an optimal movement pattern for a racing driver. Tilting the head during cornering can cause conflict between the three perceptual systems that provide information for orientation: the visual system, the vestibular system, and the proprioceptive system (Fouque et al., 1999). Consider a racing driver taking a right-hand corner on a racetrack. First, the driver rotates their head to visualize the apex approximately 1s before changing steering wheel angle to rotate the car (Land & Tatler, 2001). Second, they tilt their head to the right to align with visual road tilt (Zikovitz & Harris, 1999). Consequently, the visual reference frame of the driver no longer aligns with the visual reference frame of the track (unless there is significant camber). This could cause the driver to misjudge their heading (Treffner et al., 2002).

In addition, the head tilt of the driver will cause conflict between the proprioceptive information from left sternocleidomastoid muscle which rotates the head ("I am turning right.") and right sternocleidomastoid which tilts the head to right but also rotates the head to the left ("I am turning left.") (Bove et al., 2001; Pettorossi & Schieppati, 2014). When drivers integrate the information from the visual and vestibular systems with the information from the proprioceptive system, they could perceive that they are understeering and overcorrect.

Despite the availability of sensory information from the visual, vestibular, and proprioceptive systems, information from each system may not be equally weighted, or indeed used at all, to inform perception in all situations. Because driving is predominantly a visual task (Zikovitz & Harris, 1999), errors stemming from erroneous proprioceptive information are more likely to occur when the demands on visual attention increase. For example, when a driver intentionally follows another car to overtake (Rosalie & Malone, 2019a). Increased demands on attention have been shown to reduce driver performance (Baldisserri et al., 2014). Therefore it is critical that the coordination patterns that drivers use optimize the accuracy of each source of information integrated into their "global-array" (Stoffregen & Bardy, 2001). As a result, when one sensory system is "occupied" (e.g., vision to avoid a collision or audition to listen to team radio) the remaining senses support accurate track navigation. We have shown repeatedly that it is possible to improve driver performance and reduce driver error by decreasing head tilt during race driving. Therefore, we recommend further close investigation of the potential of our methodology to improve driver performance by understanding how the neuromuscular system of the driver responds to various tasks on track.

Limitations and Future Directions

The main limitation of our study is the small sample size. Therefore, care should be taken in generalizing our results beyond the population of amateur female racing drivers driving closed cockpit race cars. However, small sample size is a common limitation in the scientific study of on-track driver performance which should not necessarily limit translation of research findings into performance and safety benefits. Case studies (e.g., Land & Tatler, 2001) and investigations of two or three drivers within one team (e.g., Potkanowicz et al., 2020) are the norm rather than the exception. Larger cohort studies such as the one by Carlson et al. (2014) are a rarity (n = 8) and virtually unheard of at elite level (e.g., Formula 1). Cost, regulations that restrict practice and the understandable unwillingness of teams and drivers to share innovations with the potential to benefit performance all contribute to limiting the number of drivers available for a given study. Ideally, our study should be replicated with a larger cohort of drivers all of whom complete three tests: a baseline, a test with a sham seat insert that does not improve driving position, and an "active" insert that does. Drivers should complete the three tests in a random order to which both researchers and drivers are blinded. This type of design would suit a single manufacturer series, such as FIA W Series, where driver performance has greater influence on the overall outcome. If the past limitations on sample size in scientific study in motorsport continue, it's important to recognize that understanding how to achieve truly exceptional performance can be realized only through researching the performance of truly exceptional individuals (e.g., Hoogkamer et al., 2019).

Acknowledgements

The authors wish to acknowledge the following companies and individuals for their invaluable contributions to this study. Raptor Motorsports LLC for providing vehicles, off-track facilities and funding for equipment and consumables. Rotary Response and Racing LLC for providing mechanical services. The staff of Raptor Motorsports LLC for moulding the seat inserts. Inde Motorsport Ranch for providing access to the track and associated track services.

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

ORCID iD: Simon M. Rosalie

https://orcid.org/0000-0002-4392-8760

AUTO+MEDICAL SCIENCE

REFERENCES

1. Baldisserri, L., Bonetti, R., Pon, F., Guidotti, L., Losi, M. G., Montanari, R., Collina, S. (2014). Motorsport driver workload estimation in dual task scenario. Paper presented at the 6th International Conference on Advanced Cognitive Technologies and Applications. IARIA, Venice, Italy.
2. Bose, D., Segui-Gomez, S., Maria, & Crandall, J. R. (2011). Vulnerability of female drivers involved in motor vehicle crashes: an analysis of US population at risk. American Journal of Public Health, 101(12), 2368- 2373.
3. Bove, M., Diverio, M., Pozzo, T., & Schieppati, M. (2001). Neck muscle vibration disrupts steering of locomotion. Journal of Applied Physiology, 91(2), 581-588.
4. Carlson, L. A., Ferguson, D. P., & Kenefick, R. W. (2014). Physiological strain of stock car drivers during competitive racing. Journal of Thermal Biology, 44, 20-26.
5. Cifrek, M., Tonković, S., & Medved, V. (2000). Measurement and analysis of surface myoelectric signals during fatigued cyclic dynamic contractions. Measurement, 27(2), 85-92.
6. Coakwell, M. R., Bloswick, D. S., & Moser, R. (2004). High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviation, Space, and Environmental Medicine, 75(1), 68-80.
7. F1 Drivers 2021 - Hamilton, Verstappen, Vettel and more. Formula 1® - The Official F1® Website, Retrieved April 3, 2021, from https://www.formula1.com/en/drivers.html
8. Field, A. (2013). Discovering statistics using IBM SPSS statistics: Sage.
9. Fouque, F., Bardy, B. G., Stoffregen, T. A., & Bootsma, R. J. (1999). Action and intermodal information influence the perception of orientation. Ecological Psychology, 11(1), 1-43.
10. Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorts-67
11. Rosalie and Rosalie (2021) Customizing Seat Fit Improves Performance Klug, C., Hagg, G. (1999). European recommendations for surface electromyography. Roessingh Research and Development, 8(2), 13-54.
12. Hodges, P., Cresswell, A., Daggfeldt, K., & Thorstensson, A. (2000). Three dimensional preparatory trunk motion precedes asymmetrical upper limb movement. Gait & Posture, 11(2), 92-101.
13. Hodges, P., Cresswell, A., & Thorstensson, A. (1999). Preparatory trunk motion accompanies rapid upper limb movement. Experimental Brain Research, 124(1), 69-79.
14. Hoogkamer, W., Snyder, K. L., & Arellano, C. J. (2019). Reflecting on Eliud Kipchoge's marathon world record: An update to our model of cooperative drafting and its potential for a sub-2-hour performance. Sports Medicine, 49(2), 167-170.
15. Kim, M.-S. (2015). Neck kinematics and sternocleidomastoid muscle activation during neck rotation in subjects with forward head posture. Journal of Physical Therapy Science, 27(11), 3425-3428.
16. Król, H., Sobota, G., & Nawrat, A. (2007). Effect of electrode position on EMG recording in pectoralis major. Journal of Human Kinetics, 17, 105.
17. Land, M. F., & Lee, D. N. (1994). Where We Look When We Steer. Nature, 369(6483), 742-744. https://doi.org/10.1038/369742a0
18. Land, M. F., & Tatler, B. W. (2001). Steering with the head: The visual strategy of a racing driver. Current Biology, 11, 1215-1220.
19. Marshall, R., Hunting, K., & McKay, M. P. (2010). The effect of driver age on the incidence and severity of upper extremity injuries due to second generation front air bag deployment. Annals of advances in automotive medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference, 54, 215–222.
20. Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. Journal of Electromyography and Kinesiology, 13(5), 477- 489. https://doi.org/10.1016/s1050- 6411(03)00027-0
21. https://www.journalofexpertise.org Journal of Expertise / March 2021 / vol. 4, no. 1
22. Moroney, S. P., Schultz, A. B., & Miller, J. A. (1988). Analysis and measurement of neck loads. Journal of Orthopaedic Research, 6(5), 713-720.
23. Petersen, A., Barrett, R., & Morrison, S. (2008). Enhanced postural stability following driver training is associated with positive effects in vehicle kinematics during cornering. Human Factors, 50(1), 159-172.
24. Pettorossi, V. E., & Schieppati, M. (2014). Neck Proprioception Shapes Body Orientation and Perception of Motion. Frontiers in Human Neuroscience, 8(895). https://doi.org/ 10.3389/fnhum.2014.00895
25. Phinyomark, A., Limsakul, C., Hu, H., Phukpattaranont, P., & Thongpanja, S. (2012). The usefulness of mean and median frequencies in electromyography analysis. Computational Intelligence in Electromyography Analysis - A Perspective on Current Applications and Future Challenges (pp. 195-220): INTECH Open Access Publisher.
26. Pick, A. J., & Cole, D. J. (2006). Measurement of driver steering torque using electromyography. Journal of Dynamic Systems, Measurement, and Control, 128(4), 960-968.
27. Potkanowicz, E. S., Ferguson, D. P., & Greenshields, J. T. (2020). Responses of Driver-Athletes to Repeated Driving Stints. Medicine & Science in Sports & Exercise.
28. Rosalie, S. M. (2015). Is being both fast and safe all a matter of perception? Paper presented at the 27th Annual Conference of the International Council of Motorsport Sciences, Indianapolis, Indiana.
29. Rosalie, S. M. (2020). Wearable Sensors: A means to magnify the coach's eye. Paper presented at the Developing Athletes through Sport Psychology and Skill Learning, Perth, Australia.
30. Rosalie, S. M., & Malone, J. M. (2018a). The effect of a Halo-type structure on neck muscle activation of an open-cockpit race car driver training under qualifying conditions. BMJ Case Reports. https://doi.org/10.1136/bcr-2017-224013
31. Rosalie, S. M., & Malone, J. M. (2018b). Effect 68
32. Rosalie and Rosalie (2021) Customizing Seat Fit Improves Performance of halo-type frontal cockpit protection on overtaking. BMJ Case Reports, 2018. https://doi.org/10.1136/bcr-2018-225427
33. Rosalie, S. M., & Malone, J. M. (2019a). Do Racing Drivers Practice Racing? The Effect of Intentional Following on Formula Car Drivers' Steering Behavior. Journal of Expertise, 2(3), 164-183.
34. Rosalie, S. M., & Malone, J. M. (2019b). Women in motorsport: A case report of driving posture and performance after double mastectomy. Physical Therapy in Sport 36, 1-4. https:// doi.org/10.1016/j.ptsp.2018.12.005
35. Roy, S., & De Luca, C. (1989). Evolving characteristics of the median frequency of the EMG signal. Computer-aided electromyography and expert systems. Holland: Elsevier, 115-124.
36. Shek, D. T., & Ma, C. (2011). Longitudinal data analyses using linear mixed models in SPSS: concepts, procedures, and illustrations. The Scientific World Journal, 11, 42-76.
37. Singer, J. D., & Willett, J. B. (2003). Applied longitudinal data analysis. New York: Oxford Press.
38. Singmann, H., & Kellen, D. (2019). An introduction to mixed models for experimental psychology. In D. Spieler & E. Schumacher (Eds.), New methods in cognitive psychology (pp. 4-31). Routledge. https://doi.org/10.4324/9780429318405
39. Smulders, M., Naddeo, A., Cappetti, N., van Grondelle, E., Schultheis, U., & Vink, P. (2019). Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support. Applied Ergonomics, 79, 25-37.
40. Stoffregen, T. A., & Bardy, B. G. (2001). On specification and the senses. Behavioral and Brain Sciences, 24(2), 195-213.
41. Teams & Drivers - Formula 2. FIA_F2® - The Official F2® Website, Retrieved April 3, 2021, https://www.fiaformula2.com/Teams- and-Drivers
42. Teams & Drivers - Formula 3. FIAFormula3® - The Official F3® Website, Retrieved April 3, 2021, https://www.fiaformula3.com/Teams- and-Drivers
43. Trammell, T., & Flint, K. (2012). Spine fractures in drivers of open-wheel open cockpit race cars. Aspetar Sports Medicine Journal, 1(3), 196-2002.
44. Treffner, P., Barrett, R., & Petersen, A. (2002). Stability and skill in driving. Human Movement Science, 21(5-6), 749-784.
45. Ye, X., Poplin, G., Bose, D., Forbes, A., Hurwitz, S., Shaw, G., & Crandall, J. (2015). Analysis of crash parameters and driver characteristics associated with lower limb injury. Accident Analysis & Prevention, 83, 37-46.
46. Zikovitz, D. C., & Harris, L. R. (1999). Head tilt during driving. Ergonomics, 42(5), 740-746.

Appendix A. Table 3. Parameter estimates for the fixed and random effects of the seat insert on NMF of left sternocleidomastoid (LSCM), right sternocleidomastoid (RSCM), left cervical erector spinae (LCES) and right cervical erector spinae (RCES) with respect to group (Improved vs. No Improvement)

Estimates of Fixed Effects

Muscle	Group	Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
								Lower Bound	Upper Bound
LSCM	No Improvement	Time	-16.16	2.52	39170.00	-6.42	<0.001	-21.09	-11.23
		Time^2	22.87	5.85	39170.00	3.91	<0.001	11.40	34.33
		Time^3	-12.44	3.84	39170.00	-3.23	0.001	-19.97	-4.90
		Time X Condition	14.70	3.56	39170.00	4.13	<0.001	7.73	21.67
		Time^2 X Condition	-20.91	8.27	39170.00	-2.53	0.01	-37.11	-4.71
		Time^3 X Condition	8.58	5.43	39170.00	1.58	0.11	-2.07	19.23
	Improved	Time	-5.64	2.07	130.57	-2.73	0.007	-9.73	-1.55
		Time^2	11.84	4.43	107868.03	2.67	0.008	3.16	20.52
		Time^3	-8.70	2.91	107868.03	-2.99	0.003	-14.40	-2.99
		Time X Condition	9.65	2.72	107868.04	3.55	<0.001	4.33	14.98
		Time^2 X Condition	-30.69	6.31	107868.03	-4.86	<0.001	-43.06	-18.31
		Time^3 X Condition	22.01	4.15	107868.03	5.30	<0.001	13.87	30.14
RSCM	No Improvement	Time	36.92	3.25	39170.00	11.36	<0.001	30.55	43.29
		Time^2	-92.93	7.55	39170.00	-12.31	<0.001	-107.73	-78.13
		Time^3	60.72	4.96	39170.00	12.23	<0.001	50.99	70.45
		Time X Condition	-22.40	4.59	39170.00	-4.88	<0.001	-31.40	-13.40
		Time^2 X Condition	46.31	10.67	39170.00	4.34	<0.001	25.40	67.23
		Time^3 X Condition	-27.13	7.01	39170.00	-3.87	<0.001	-40.88	-13.38
	Improved	Time	-12.24	2.13	395.13	-5.76	<0.001	-16.42	-8.06
		Time^2	23.03	4.73	107868.08	4.87	<0.001	13.76	32.30
		Time^3	-11.68	3.11	107868.08	-3.76	<0.001	-17.77	-5.59
		Time X Condition	10.66	2.90	107868.09	3.68	<0.001	4.98	16.35
		Time^2 X Condition	-31.25	6.74	107868.08	-4.64	<0.001	-44.46	-18.04
		Time^3 X Condition	19.87	4.43	107868.08	4.48	<0.001	11.18	28.55
LCES	No Improvement	Time	-24.38	3.19	39170.00	-7.63	<0.001	-30.64	-18.12
		Time^2	48.57	7.42	39170.00	6.54	<0.001	34.02	63.12
		Time^3	-25.43	4.88	39170.00	-5.21	<0.001	-35.00	-15.87
		Time X Condition	29.31	4.51	39170.00	6.49	<0.001	20.46	38.16
		Time^2 X Condition	-60.49	10.49	39170.00	-5.77	<0.001	-81.05	-39.93
		Time^3 X Condition	29.68	6.90	39170.00	4.30	<0.001	16.16	43.19
	Improved	Time	4.58	2.78	23.46	1.65	0.11	-1.17	10.34
		Time^2	-14.74	5.20	107867.99	-2.83	0.005	-24.93	-4.55
		Time^3	11.23	3.42	107867.99	3.28	0.001	4.53	17.93
		Time X Condition	-18.11	3.19	107867.99	-5.68	<0.001	-24.36	-11.86
		Time^2 X Condition	42.29	7.41	107867.99	5.71	<0.001	27.76	56.81
		Time^3 X Condition	-30.46	4.87	107867.99	-6.25	<0.001	-40.01	-20.91
RCES	No Improvement	Time	3.32	2.79	39170.00	1.19	0.23	-2.15	8.80
		Time^2	-12.45	6.49	39170.00	-1.92	0.05	-25.16	0.26
		Time^3	10.13	4.26	39170.00	2.38	0.02	1.78	18.49
		Time X Condition	6.23	3.94	39170.00	1.58	0.11	-1.50	13.96
		Time^2 X Condition	-4.13	9.17	39170.00	-0.45	0.65	-22.10	13.84
		Time^3 X Condition	-0.04	6.03	39170.00	-0.01	1.00	-11.85	11.78
	Improved	Time	-2.11	2.51	15.32	-0.84	0.41	-7.44	3.23
		Time^2	-7.16	4.37	107868.04	-1.64	0.10	-15.72	1.39
		Time^3	9.87	2.87	107868.04	3.44	0.001	4.25	15.50
		Time X Condition	13.95	2.68	107868.05	5.21	<0.001	8.70	19.20
		Time^2 X Condition	-19.60	6.22	107868.04	-3.15	0.002	-31.80	-7.40
		Time^3 X Condition	7.59	4.09	107868.04	1.85	0.06	-0.43	15.61

Appendix B. Table 4. Parameter estimates for the fixed and random effects of the seat insert on NMF of left anterior deltoid (LAD), right anterior deltoid (RAD), left pectoralis major (LPM), and right pectoralis major (RAD) with respect to group (Improved vs. No Improvement).

Estimates of Fixed Effects

Muscle	Group	Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
								Lower Bound	Upper Bound
LAD	No Improvement	Time	-7.31	2.35	39170.00	-3.12	0.002	-11.91	-2.71
		Time^2	22.92	5.45	39170.00	4.20	<0.001	12.24	33.61
		Time^3	-16.92	3.58	39170.00	-4.72	<0.001	-23.94	-9.89
		Time X Condition	-11.08	3.32	39170.00	-3.34	0.001	-17.58	-4.59
		Time^2 X Condition	21.97	7.70	39170.00	2.85	0.004	6.87	37.07
		Time^3 X Condition	-13.31	5.06	39170.00	-2.63	0.01	-23.23	-3.38
	Improved	Time	-10.99	1.67	2645.74	-6.57	<0.001	-14.27	-7.71
		Time^2	25.48	3.83	107867.81	6.65	<0.001	17.97	32.99
		Time^3	-17.20	2.52	107867.81	-6.83	<0.001	-22.14	-12.26
		Time X Condition	-1.05	2.35	107867.83	-0.45	0.65	-5.66	3.55
		Time^2 X Condition	0.16	5.46	107867.81	0.03	0.98	-10.55	10.87
		Time^3 X Condition	1.34	3.59	107867.81	0.37	0.71	-5.70	8.38
RAD	No Improvement	Time	-9.87	2.29	39170.00	-4.30	<0.001	-14.36	-5.37
		Time^2	15.61	5.33	39170.00	2.93	0.003	5.17	26.05
		Time^3	-8.36	3.50	39170.00	-2.39	0.02	-15.22	-1.49
		Time X Condition	13.49	3.24	39170.00	4.16	<0.001	7.14	19.84
		Time^2 X Condition	-18.67	7.53	39170.00	-2.48	0.01	-33.43	-3.91
		Time^3 X Condition	7.90	4.95	39170.00	1.60	0.11	-1.80	17.60
	Improved	Time	15.06	1.84	609.95	8.19	<0.001	11.45	18.67
		Time^2	-34.05	4.13	107866.35	-8.24	<0.001	-42.15	-25.96
		Time^3	21.90	2.72	107866.35	8.06	<0.001	16.57	27.22
		Time X Condition	-19.05	2.53	107866.38	-7.52	<0.001	-24.02	-14.09
		Time^2 X Condition	25.69	5.89	107866.35	4.36	<0.001	14.15	37.23
		Time^3 X Condition	-10.97	3.87	107866.35	-2.83	0.005	-18.55	-3.38
LPM	No Improvement	Time	-4.46	1.43	39170.00	-3.11	0.002	-7.27	-1.65
		Time^2	9.98	3.33	39170.00	3.00	0.003	3.45	16.51
		Time^3	-6.51	2.19	39170.00	-2.97	0.003	-10.81	-2.22
		Time X Condition	2.94	2.03	39170.00	1.45	0.15	-1.03	6.91
		Time^2 X Condition	-5.69	4.71	39170.00	-1.21	0.23	-14.92	3.53
		Time^3 X Condition	3.30	3.09	39170.00	1.07	0.29	-2.76	9.37
	Improved	Time	-2.70	2.03	3001.87	-1.33	0.18	-6.68	1.27
		Time^2	4.89	4.65	107867.99	1.05	0.29	-4.22	14.00
		Time^3	-1.76	3.06	107867.99	-0.58	0.56	-7.75	4.23
		Time X Condition	-0.84	2.85	107868.01	-0.30	0.77	-6.43	4.74
		Time^2 X Condition	2.84	6.62	107867.99	0.43	0.67	-10.15	15.82
		Time^3 X Condition	-2.68	4.35	107867.99	-0.62	0.54	-11.22	5.85
RPM	No Improvement	Time	-12.35	1.79	39170.00	-6.88	<0.001	-15.87	-8.84
		Time^2	25.26	4.17	39170.00	6.06	<0.001	17.08	33.44
		Time^3	-14.73	2.74	39170.00	-5.37	<0.001	-20.10	-9.35
		Time X Condition	19.09	2.54	39170.00	7.52	<0.001	14.12	24.06
		Time^2 X Condition	-36.39	5.89	39170.00	-6.17	<0.001	-47.94	-24.84
		Time^3 X Condition	20.45	3.87	39170.00	5.28	<0.001	12.85	28.04
	Improved	Time	5.37	1.49	587.65	3.61	<0.001	2.45	8.29
		Time^2	-14.84	3.34	107867.71	-4.44	<0.001	-21.39	-8.29
		Time^3	11.82	2.20	107867.71	5.38	<0.001	7.51	16.12
		Time X Condition	-8.74	2.05	107867.72	-4.27	<0.001	-12.76	-4.72
		Time^2 X Condition	23.22	4.76	107867.71	4.88	<0.001	13.89	32.55
		Time^3 X Condition	-16.63	3.13	107867.71	-5.31	<0.001	-22.77	-10.50

Appendix C. Table 5. Parameter estimates for the fixed and random effects of the seat insert on NMF of left lumbar erector spinae (LLES), right lumbar erector spinae (RLES), left rectus abdominis (LRA), right rectus abdominis (RRA), left transversus abdominis (LTA) and right transversus abdominis (RTA) with respect to group (Improved vs. No Improvement)

Estimates of Fixed Effects

Muscle	Group	Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
								Lower Bound	Upper Bound
LLES	No Improvement	Time	-3.29	2.66	39170.00	-1.24	0.22	-8.49	1.92
		Time^2	12.98	6.17	39170.00	2.10	0.04	0.88	25.07
		Time^3	-9.78	4.06	39170.00	-2.41	0.02	-17.73	-1.83
		Time X Condition	2.58	3.75	39170.00	0.69	0.49	-4.77	9.94
		Time^2 X Condition	-14.24	8.72	39170.00	-1.63	0.10	-31.33	2.85
		Time^3 X Condition	14.04	5.73	39170.00	2.45	0.01	2.81	25.27
LLES	Improved	Time	-5.58	2.38	17.49	-2.35	0.03	-10.58	-0.58
		Time^2	11.66	4.24	107867.98	2.75	0.006	3.36	19.97
		Time^3	-3.10	2.79	107867.98	-1.11	0.27	-8.56	2.36
		Time X Condition	-1.49	2.60	107867.98	-0.57	0.57	-6.58	3.61
		Time^2 X Condition	2.30	6.04	107867.98	0.38	0.70	-9.54	14.13
		Time^3 X Condition	-3.09	3.97	107867.98	-0.78	0.44	-10.87	4.69
RLES	No Improvement	Time	-11.27	2.73	39170.00	-4.13	<0.001	-16.63	-5.92
		Time^2	10.49	6.35	39170.00	1.65	0.10	-1.96	22.94
		Time^3	-5.96	4.18	39170.00	-1.43	0.15	-14.14	2.22
		Time X Condition	-7.56	3.86	39170.00	-1.96	0.05	-15.13	0.01
		Time^2 X Condition	42.49	8.98	39170.00	4.73	<0.001	24.90	60.09
		Time^3 X Condition	-28.47	5.90	39170.00	-4.83	<0.001	-40.04	-16.91
RLES	Improved	Time	-6.74	1.67	64.08	-4.03	<0.001	-10.08	-3.40
		Time^2	12.84	3.45	107868.00	3.72	<0.001	6.08	19.59
		Time^3	-6.37	2.27	107868.00	-2.81	0.005	-10.81	-1.93
		Time X Condition	6.98	2.11	107868.00	3.30	0.001	2.83	11.12
		Time^2 X Condition	-21.35	4.91	107868.00	-4.35	<0.001	-30.98	-11.72
		Time^3 X Condition	17.69	3.23	107868.00	5.48	<0.001	11.36	24.02
LRA	No Improvement	Time	-46.86	3.90	39170.00	-12.02	<0.001	-54.51	-39.22
		Time^2	112.33	9.06	39170.00	12.40	<0.001	94.57	130.09
		Time^3	-62.09	5.96	39170.00	-10.42	<0.001	-73.77	-50.41
		Time X Condition	47.29	5.51	39170.00	8.58	<0.001	36.49	58.09
		Time^2 X Condition	-125.20	12.81	39170.00	-9.78	0.001	-150.30	-100.10
		Time^3 X Condition	73.07	8.42	39170.00	8.68	<0.001	56.57	89.57
LRA	Improved	Time	-3.91	2.27	412.03	-1.73	0.09	-8.36	0.54
		Time^2	-17.52	5.05	107868.08	-3.47	0.001	-27.41	-7.63
		Time^3	22.96	3.32	107868.08	6.92	<0.001	16.46	29.46
		Time X Condition	3.34	3.09	107868.09	1.08	0.28	-2.72	9.41
		Time^2 X Condition	24.03	7.19	107868.08	3.34	0.001	9.94	38.13
		Time^3 X Condition	-29.19	4.73	107868.08	-6.17	<0.001	-38.45	-19.92
RRA	No Improvement	Time	-13.97	4.02	39170.00	-3.48	0.001	-21.84	-6.10
		Time^2	23.73	9.33	39170.00	2.54	0.01	5.44	42.02
		Time^3	-12.10	6.13	39170.00	-1.97	0.05	-24.12	-0.08
		Time X Condition	-7.79	5.67	39170.00	-1.37	0.17	-18.91	3.34
		Time^2 X Condition	27.95	13.19	39170.00	2.12	0.03	2.10	53.79
		Time^3 X Condition	-22.84	8.67	39170.00	-2.63	0.008	-39.83	-5.85
RRA	Improved	Time	-23.75	3.21	9.68	-7.39	<0.001	-30.94	-16.56
		Time^2	45.97	4.98	107867.99	9.23	<0.001	36.21	55.73
		Time^3	-27.84	3.27	107867.99	-8.50	<0.001	-34.25	-21.42
		Time X Condition	12.33	3.06	107867.99	4.04	<0.001	6.34	18.32
		Time^2 X Condition	-8.13	7.10	107867.99	-1.15	0.25	-22.05	5.79
		Time^3 X Condition	1.20	4.67	107867.99	0.26	0.80	-7.95	10.35
LTA	No Improvement	Time	-22.79	3.58	39170.00	-6.37	<0.001	-29.80	-15.78
		Time^2	189.50	8.31	39170.00	22.80	<0.001	173.20	205.79
		Time^3	-137.95	5.46	39170.00	-25.24	<0.001	-148.66	-127.24
		Time X Condition	22.90	5.06	39170.00	4.53	<0.001	12.99	32.81
		Time^2 X Condition	-190.88	11.75	39170.00	-16.25	<0.001	-213.91	-167.86
		Time^3 X Condition	137.28	7.72	39170.00	17.78	<0.001	122.14	152.41
LTA	Improved	Time	-2.10	2.38	27.30	-0.88	0.39	-6.98	2.78
		Time^2	0.82	4.53	107867.95	0.18	0.86	-8.05	9.70
		Time^3	2.59	2.98	107867.95	0.87	0.38	-3.24	8.43
		Time X Condition	-20.45	2.78	107867.95	-7.36	<0.001	-25.89	-15.00
		Time^2 X Condition	52.31	6.46	107867.95	8.10	<0.001	39.65	64.96
		Time^3 X Condition	-36.89	4.24	107867.95	-8.69	<0.001	-45.21	-28.57
RTA	No Improvement	Time	2.74	3.76	39170.00	0.73	0.47	-4.63	10.11
		Time^2	-51.17	8.73	39170.00	-5.86	<0.001	-68.29	-34.06
		Time^3	54.51	5.74	39170.00	9.49	<0.001	43.26	65.77
		Time X Condition	14.09	5.31	39170.00	2.65	0.008	3.68	24.50
		Time^2 X Condition	-13.47	12.34	39170.00	-1.09	0.28	-37.66	10.73
		Time^3 X Condition	-12.83	8.11	39170.00	-1.58	0.11	-28.73	3.07
RTA	Improved	Time	-5.18	1.90	107.40	-2.73	0.007	-8.94	-1.42
		Time^2	4.70	4.04	107867.84	1.17	0.24	-3.21	12.62
		Time^3	-1.21	2.65	107867.84	-0.46	0.65	-6.41	3.99
		Time X Condition	11.58	2.48	107867.85	4.68	<0.001	6.73	16.43
		Time^2 X Condition	-14.96	5.75	107867.84	-2.60	0.01	-26.23	-3.68
		Time^3 X Condition	7.47	3.78	107867.84	1.98	0.05	0.06	14.88

Estimates of the Random Effects

Muscle	Group	Parameter	Estimate	Std. Error	Wald Z	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
LSCM	Improved	Variance in Intercepts	30.48	24.90	1.22	0.22	6.14	151.20
		Variance in Time		1.58	1.20	0.23	0.37	9.75
		Covariance	1.89		0.48	0.63	-0.71	0.89
RSCM	Improved	Variance in Intercepts	64.80	52.94	1.22	0.22	13.07	321.30
		Variance in Time	1.13	0.96	1.17	0.24	0.21	6.02
		Covariance	0.09	0.59	0.16	0.87	-0.79	0.85
LCES	Improved	Variance in Intercepts	8.40	6.87	1.22	0.22	1.69	41.77
		Variance in Time	8.24	6.79	1.21	0.23	1.64	41.46
		Covariance	-0.82	0.19	-4.40	<0.001	-0.98	-0.03
RCES	Improved	Variance in Intercepts	1.81	1.49	1.21	0.23	0.36	9.10
		Variance in Time	8.28	6.82	1.21	0.22	1.65	41.61
		Covariance	0.67	0.32	2.09	0.04	-0.33	0.96

Estimates of the Random Effects

Muscle	Group	Parameter	Estimate	Std. Error	Wald Z	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
LLES	Improved	Variance in Intercepts	20.99	17.15	1.22	0.22	4.23	104.15
		Variance in Time	6.97	5.73	1.22	0.22	1.39	34.92
RLES	Improved	Variance in Intercepts	13.61	11.13	1.22	0.22	2.74	67.57
		Variance in Time	1.78	1.48	1.20	0.23	0.35	9.08
LRA	Improved	Variance in Intercepts	31.07	25.40	1.22	0.22	6.26	154.19
		Variance in Time	1.25	1.07	1.17	0.24	0.23	6.70
RRA	Improved	Variance in Intercepts	74.09	60.52	1.22	0.22	14.94	367.35
		Variance in Time	17.16	14.07	1.22	0.22	3.44	85.59
LTA	Improved	Variance in Intercepts	5.73	4.70	1.22	0.22	1.15	28.61
		Variance in Time	5.57	4.59	1.21	0.23	1.10	28.04
RTA	Improved	Variance in Intercepts	4.62	3.79	1.22	0.22	0.93	23.03
		Variance in Time	1.75	1.47	1.19	0.24	0.33	9.13

+ CALL FOR SUBMISSIONS

Every issue of AUTO+ Medical contains a research paper or injury case study that takes a scientific look at the sport.

All submissions are welcome so if you have a study that you feel would be suitable for publication in future issues of AUTO+ Medical, please send it to: automedical@fia.com

For each submission please include a summary of the research and all necessary contact information.

The editorial board will evaluate each submission before it is accepted for use in the magazine.