Optimising Motorcycle Circuit Racing Rider's Performance

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Abstract

Performance in motorcycle circuit racing is typically considered as the summation of interactions between rider, motorcycle, tyres, and environment. The distinct contributions of these parts to performance remain unmeasurable, and the influence of the human component in the final outcome is quantitatively unknown, however nonetheless important. Compared to the technological developments of the motorcycles and the investments dedicated to the engineering and mechanical components of performance, the scientific research studying the human factors involved in this sport is minimal, and relative strategies aiming at racer's development are mostly unpublished.

This thesis aimed at advancing knowledge and professional practice regarding the human factors in circuit race motorcycling. The ultimate goal of this doctoral research was to provide a scientific basis for refining rider-training programs specifically designed to support and improve riders' performance. A multidisciplinary approach was used to answer the research question "which physical and cognitive factors are important in optimising the rider's performance in motorcycle circuit racing competitions?" Therefore, profiling the physiological requirements, the mechanical stresses, and the psychological strategies with the aggregate purpose to improve the understanding of the rider as an athlete has been at the core of this project.

The foundational knowledge about the performance was established by reviewing the current literature and analysing the characteristics of top-level performance; the mechanical stress was investigated by profiling the physical load of top-level competitions and measuring the inertial stresses of riders during national and international races; the thermal stress of racing in hot environments and potential pre-cooling strategies were studied to deepen the understanding about the physiological requirements of racing; the psychological skills and strategies used by riders in competition and practice settings were measured; and, the preparation practices adopted by licensed riders were investigated to complete a well-rounded comprehension of the sport and its demands.

Findings revealed that human performance in motorcycle circuit racing is a complex interaction of specific skills and abilities and high performance riders are exposed to: a) substantial volume of high intensity actions due to the negative/positive accelerations and technical movements experienced during racing (i.e. 175 brakes and 372 leans to corner per race, with peak inertial stresses over 1000 N); b) thermal stress experienced during competitions in hot environment (i.e. gastrointestinal temperature reaching 40.1°C); and, c) potential injuries due to crashes (i.e. 13% of starters suffered a crash each race) or localised muscular overload i.e. forearm chronic exertional

compartmental syndrome. Moreover, riders are required to possess coping strategies in relation to the magnitude of the psychological stress of racing (i.e. emotional control); and preparation practices at national level revealed that there is a tendency to lack professional guidance in riders' training programs.

Aspiring high performance motorcycle circuit racers are recommended to engage in specific multidisciplinary training programs to minimize the effects of muscular and metabolic fatigue during competition, to optimize body composition, to prevent risks of injuries and overloads, to minimize the impact of heat on performance, to improve their technical and mental skill-set and capacities, and to manage successfully their investments towards their racing career.

Acknowledgments

Deciding to start a second journey to achieve another Doctorate, at the age of almost 40, might be perceived as a hazardous choice by many. Indeed it is. But obviously, I would never had embarked on such a mission without knowing I had valuable people by my side.

My most profound thanks are given to my supervisory team: Professor John Cronin and Professor Paul Laursen, for their guidance, reliability, professional support and genuine friendship.
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Thank you to the people that hold a very special place in my heart. I am grateful to Bibbina, my number 1 supporter. Thank you for respecting my passions, believing in my dreams, being by my side. I love you Barbara.

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Barbara and I are very grateful to the people that became our family in Aotearoa New Zealand. Thank you to Dee, John, Marcello and Murphy.

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Attestation of Authorship

“I hereby declare that this submission titled 'Optimising Motorcycle Circuit Racing Rider's Performance' is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning”.

Emanuele D’Artibale PhD

Co-authored Works

Chapter 2. Human performance in motorcycle road racing: a review of the literature. *Sports Medicine* (2018).
(D'Artibale E: 90%; Laursen P: 5%; Cronin J: 5%).

Chapter 3. Trend analysis of 20 years of FIM road racing Gran Prix motorcycle world championship. *International Journal of Sports Physiology and Performance* (2018).
(D'Artibale E: 87%; Rohan M: 8%; Cronin J: 5%).

Chapter 4. Profiling the physical load on riders of top-level motorcycle circuit racing. *Journal of Sports Sciences* (2018).
(D'Artibale E: 90%; Laursen P: 5%; Cronin J: 5%).

Chapter 5. Inertial stresses of national and international motorcycle circuit racing riders. (*Currently under revision before publication*).
(D'Artibale E: 85%; Neville J: 7.5%; Cronin J: 7.5%).

Chapter 6. Core temperature and pre-cooling strategies in motorcycle circuit racing riders during official competitions. (*To be submitted for publication*).
(D'Artibale E: 87%; Laursen P: 8%; Cronin J: 5%).

We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

Primary Supervisor: Prof John B. Cronin

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Contributor: Dr Maheswaran Rohan

Contributor: Dr Jonathon Neville

Publications Arising from the Thesis

D'Artibale E, Laursen P, Cronin JB. Human Performance in Motorcycle Road Racing: a Review of the Literature. Sports Medicine. 2018; Jun;48(6):1345-1356. doi: 10.1007/s40279-018-0895-3

D'Artibale E, Rohan M, Cronin JB. Trend analysis of 20 years of FIM road racing Gran Prix motorcycle world championship. International Journal of Sports Physiology and Performance. 2018; Jul 1;13(6):795-801. doi: 10.1123/ijspp.2017-0664

D'Artibale E, Laursen P, Cronin J. Profiling the physical load on riders of top-level motorcycle circuit racing. Journal of Sports Sciences. 2018; May;36(9):1061-1067. doi: 10.1080/02640414.2017.1355064

D'Artibale E, Neville J, Cronin J. Inertial stresses of national and international motorcycle circuit racing riders. (in revision before publication)

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D'Artibale E, Cronin JB. Measure of psychological skills via TOPS2 in motorcycle circuit racing riders. **(**To be submitted for publication)

D'Artibale E, Laursen P, Cronin JB. Preparation practices of riders competing in motorcycle circuit racing in two different continents. **(**To be submitted for publication)

Ethics Approval

For Chapter 5 (Inertial stresses of national and international motorcycle circuit racing riders), ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC), reference number 16/109.

For Chapter 6 (Core temperature and pre-cooling strategies in motorcycle circuit racing riders during official competitions), ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC), reference number 16/92.

For Chapter 7 (Measure of psychological skills via TOPS2 in circuit race motorcycling riders), ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC), reference number 15/330.

For Chapter 8 (Preparation practices of riders competing in motorcycle circuit racing), ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC), reference number 15/327.

Originals in Appendix A.

Chapter 1 – Introduction

Rationale of the Thesis

As common in motorsports, the final performance in motorcycle circuit racing arises from the summation and interaction of three main performing elements: the rider, the motorcycle (i.e., chassis, engine, suspensions, brakes, etc.) and the tyres, integrating with the environment. The distinct contributions of these parts to performance remain unmeasurable, particularly when the competing motorcycles are not identical, and the influence of the human component in the final outcome is quantitatively unknown. Despite these limitations it is undeniable that the capabilities of the rider, in conjunction with the characteristics of his/her motorcycle and the circuits, determine to some extent the quality of the performance outcome. However, the human side of motorcycle racing has received little attention from the scientific community in comparison with the research dedicated to the motorcycle. In fact, considering the significant investments made in the development of the motorcycle, the business interests of manufacturers, and the paucity of published research focused on the riders, a bike-centred mentality appears to be prevalent in this sport.

Development of materials (i.e. parts, tyres, brakes, asphalts), advancement in motorcycle engineering, aerodynamics and electronics, and improvements in protective gear and environmental safety (i.e. track configuration) has resulted in faster and fiercer competition (D'Artibale, Di Spensa, Di Cagno, & Calcagno, 2011; Lippi, Salvagno, Franchini, & Guidi, 2007), likely resulting in greater physical and mental stresses experienced by the riders. Despite the lack of evidence-based research, technical skills seem to be considered more important than physiological characteristics in motorsports (Gobbi, Francisco, Tuy, & Kvitne, 2005), as a result, only a few researchers have investigated the physical and physiological demands of training and competition (Sánchez-Muñoz et al., 2011). The results from these studies suggest that motorcycle circuit racing imposes a substantial load on the riders, who should have adequate fitness to delay the onset of fatigue during races (D’Artibale, Tessitore, & Capranica, 2008; D’Artibale, Tessitore, Tiberi, & Capranica, 2007; Filaire, Filaire, & Le Scanff, 2007), however riders remain understudied and guidelines for optimising their performance are only partially known.

While physical conditioning and mental preparation are believed to be essential for the motorsport athlete (Klarica, 2001), it is difficult to discern this with any clarity based on the currently status of published literature, and the underused sports medicine and evidence-based human-focused research. The reasons for this can most likely be attributed to the difficulty of using experimental apparatus in such unique competitive settings, combined with the commercial interests of motorcycle manufacturers and, overall, the tendency for most racing teams to operate in strict secrecy so as to maintain a competitive advantage. However, technology in the sport sciences is rapidly evolving, so that some technical, physical and tactical aspects of a rider's performance can be measured and ultimately used to enhance human performance and therefore the contribution to the final outcome in motorcycle racing.

Purpose of the Research

This research project aims at advancing knowledge and professional practice regarding the human factors in the field of motorcycle circuit racing. Indeed, findings from this research aim at:

1) providing scientifically-based information regarding the physical requirements of motorcycle circuit racing that competitive riders are most likely to benefit from; and,
2) solidifying the foundational knowledge about the human performance in this sport, needed to design specific training programs for motorcycle circuit racers, which is expected to lead to performance and safety enhancement during competitions.

Given the lack of published research profiling the riders and the associated physiological and psychological stress, this research aims at offering a unique resource for riders and teams aiming to enhance their performance through the development of human factors. To answer the overarching question "which physical and cognitive factors are important in optimising the rider's performance in motorcycle circuit racing competitions?", this thesis investigated the performance in motorcycle circuit racing using a multidisciplinary approach.

The objectives of better understanding this high-risk sport - which includes the interaction of the athlete with a powered machine, were built upon a progressive set of goals in different areas:

- Preparing a synthesis of the scientific literature focusing on human performance in motorcycle road racing to provide both a comprehensive understanding of the rider's human performance requirements and directions for future research (Chapter 2);
- Analysing and describing how the performance characteristics of the top class in the sport have changed over the last 20 years and quantifying potential interactions among race data (Chapter 3);
- Quantifying the physical stress experienced by top-level riders by analysing race results alongside kinematic data from top-class competitions (Chapter 4);
- Examining the relationships between performance-related variables such as crash events, speed of racing and environmental conditions in top-class competitions (Chapters 3 and 4);
- Quantifying the negative and positive accelerations that riders experience during changes of speed (i.e. braking actions and corner exits), to estimate the forces experienced on their centre of mass during competitions (Chapter 5);
- Investigating potential differences between the inertial loads of the entry-level and mid class categories, as well as determining potential relationships with the ranking level or experience of riders (Chapter 5);
- Quantifying the thermal stress of riders during official competitions in hot environments and

describing the effects of pre-cooling strategies (Chapter 6);

- Measuring the psychological skills and strategies used by riders in competition and during practice (Chapter 7);
- Describing how licensed riders in New Zealand and in Italy currently prepare for competitions (Chapter 8).

The ultimate goal of this doctoral research is to provide a scientific base for refining rider-training programs that are specifically designed to support and improve riders' performance. Application of scientifically-based findings into training practice will support the development of athletes competing in circuit race motorcycling events.

Significance of the Thesis

This research project takes place by engaging and deepening relationships with sport-industry, business and communities. Indeed, the research project is developed in partnership with Kiwi agency WIL Sport Management based in Taupo (NZ), which is actively engaged in assisting local athletes to become podium and International Series winners through: athlete management, consultancy services, sponsorship and event management. Through this direct cooperation, and the endorsement of Motorcycling New Zealand (for the study in Chapter 8), young New Zealand riders have the opportunity to be the first recipients of these new findings and potential interventions.

Due to the paucity of published research focusing on the rider and measuring the demands of the racing performance, this thesis and the publications arising from it represent a valuable contribution to the topic, establishing a needed base for future investigations and potential experimental interventions. Answering the overarching question of this thesis provides a solid foundation, still unavailable from the scientific literature, for designing programs aiming at the development of athletes competing in this sport. Both professional riders and young beginners, as well as National Motorcycling Federations and coaches, can benefit from the identification of the factors important for human performance enhancement. By analysing potential strategies for injury prevention and applying interventions throughout a training program including crash-skills development, the importance of safety in this high-risk sport is also addressed.

In addition to the contribution of scientific literature, application of scientifically-based findings into training practice will support the design and rationale of riders' development programs, and the most relevant potential benefit for athletes in the sport of motorcycle racing is improved human performance and safety.

Structure of the Thesis

The mission to answer the overarching question was organised in three sections (Figure 1.1). The first section was designed to understand the rider's performance by reviewing the current literature (Chapter 2), analysing the performance of top-level riders (Chapters 3 and 4), and then profiling populations of riders in different areas related to performance (i.e. physiological, mechanical and psychological activities) (Chapters 5, 6 and 7). Following the establishment of the foundational knowledge about the performance, the second step aimed to profile the current approaches to preparation of riders in different geographical locations in the world (Chapter 8). The final portion of the thesis was dedicated to summarising findings, to suggest answers to the overarching question with practical applications, and to indicate potential directions for future research (Chapter 9).

Please consider that some repetition may appear throughout the thesis, due to the thesis format, which is a collection of publications.

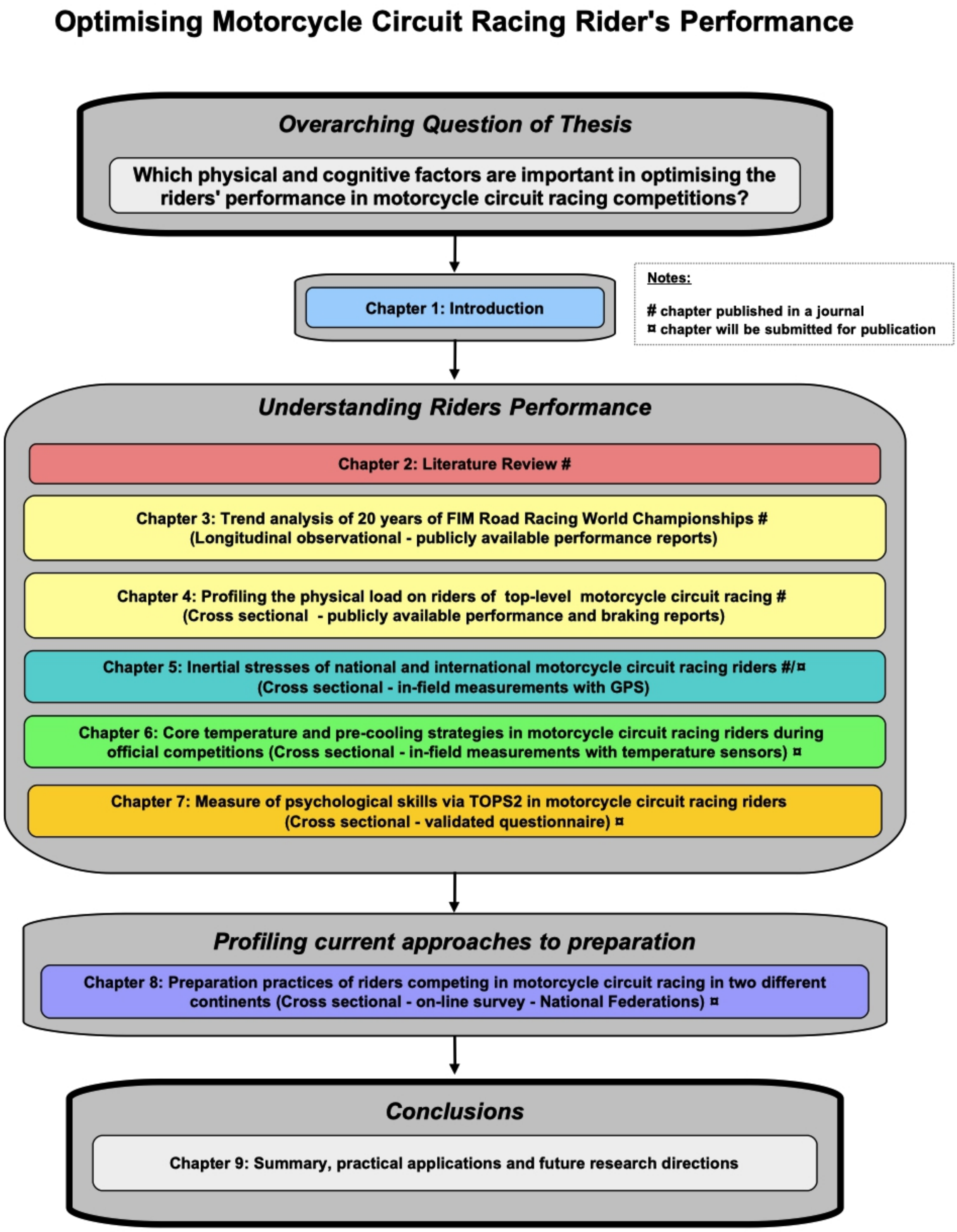

Figure 1.1. Thesis flowchart.

Chapter 2 – Human performance in motorcycle road racing: a review of the literature.

This chapter comprises the following publication in *Sports Medicine.*

Reference:

D'Artibale, E., Laursen, P., & Cronin, J.B. (2018). Human Performance in Motorcycle Road Racing: a Review of the Literature. *Sports Medicine, 48*(6), 1345-1356. doi: 10.1007/s40279-018-0895-3

Author contribution: D'Artibale E: 90%; Laursen P: 5%; Cronin J: 5%.

Introduction

The sport and focus

The sport of motorcycling is popular globally, 113 National Motorcycle Federations across six continental unions are currently affiliated with the FIM (Fédération Internationale de Motocyclisme), which is officially recognised by the IOC (International Olympic Committee) since the 2000 Olympic Games in Sydney. Competitions in six different disciplines (Road racing, Motocross, Trial, Enduro, Cross-country rallies and Speedway track racing) are organized at local, national and international level. Throughout all categories and disciplines, a total of 59 FIM World Championships and Prizes are currently held every year around the globe (Fédération Internationale de Motocyclisme, 2017).

Road race motorcycling competitions are races, where competitors riding appropriate motorcycles, after an organised collective start procedure, race simultaneously on asphalt-surfaced tracks, and compete to finish a known quantity of laps (time or distance in endurance races) faster than their opponents. With the exception of public road events, races are held on purpose-built circuits where strict safety standards are implemented, and appropriate facilities host a multitude of riders, operators and spectators.

Established as a world-level competition series in 1949, the FIM Road Racing World Championship Grand Prix is the oldest motorsport championship in the world. Currently, top level competitions such as GP or Superbike World Championships (i.e. prototype motorcycles or commercial production models, respectively) attract more than 2.4 million people through the gates of the circuits per season, and up to 200,000 spectators gather for the most spectacular events that are broadcast live in more than 200 countries and territories, reaching a cumulative audience of 460 million viewers and involving more than 13,000 media personnel throughout the season (Dorna

WSBK Organization, 2017; MotoGP™, 2015; WorldSBK, 2012).

Although competitions are organized in categories and age restrictions are applied, road race motorcycling is one of very few sports where regulations do not segregate male and female athletes. While the disciplines of motocross, enduro and trial have official international prizes reserved to female riders, road race motorcycling, with the exception of a few national series or rare international events, has historically not differentiated the gender of the performer at any level of competition.

Aim and methods

The aim of this review is to provide a synthesis of the scientific literature that has focused on human performance in motorcycle road racing. The ultimate goal of our review is to provide a comprehensive understanding of the rider's human performance requirements as well as directions for future research.

The literature search process was performed on December 2015 (updates searched on January 2018) on three electronic databases: PubMed, Sportdiscus, and PsycARTICLES. Different keyword combinations were applied between "racing", "motorsports", "motorcycle", "motorcycling", "riders", "road race", "competitions" and, "performance". To overcome the rigidity of the mechanistic search and to allow the identification of relevant papers not identified during the electronic search, the snowballing technique was also applied.

To be considered for inclusion in this review, studies had to meet the following selection criteria: I) to be focused on competitive motorcycle road racing; II) to include directly or indirectly (i.e. retrospective stats, racing performances) licensed riders as participants; III) to be peer-reviewed journal articles, conference proceedings, books, or book chapters; and, IV) to have at least an English written abstract.

Science on riders

The issues with research

As common in motorsports, the final performance in road race motorcycling arises from the summation and interaction of three main performing elements: the rider, the motorcycle (i.e. chassis, engine, suspensions, brakes) and the tyres, integrating with the environment. The distinct contributions of these parts to performance remain unmeasurable, in particular when the competing motorcycles are not identical, the influence of the human component in the final outcome is quantitatively unknown. Considering the significant investments made in the development of the motorcycle, the business interests of manufacturers, and the paucity of published research focused on the riders, a bike-centered mentality is prevalent in this sport (D'Artibale, Laursen, & Cronin, 2018a; D'Artibale et al., 2008; Sánchez-Muñoz et al., 2011).

A vast number of popular publications have been dedicated to racing motorcycles, successful riders, riding techniques and popular competition series, however, in regards to the analysis of the human performance in motorcycle road racing, the literature is scarce, and methods focusing on performance development are unpublished. The paucity of published work on the human components of racing is likely attributed to the following factors:

- Measurement devices must not interfere with the safety and the ecology of rider performance.
- In the competitive setting, data collection must conform with strict rules of the organizers (Club, National or International Federations) or track facilities.
- The unique setting of the competition event means having “friendly matches” or proper simulations problematic. Test riding sessions (i.e. individual practice) can be organized, but race

mode is not replicable.

- Laboratory simulations of motorcycle racing cannot exactly recreate the inertial stresses and the hormonal/emotional/cognitive activity of real racing.
- Professional motorsport teams are extremely reluctant to allow the collection of experimental data on their riders, especially given the perception that data will be shared, which could be advantageous to their opponents.
- Potential research performed from motorcycle manufacturers, racing equipment companies, racing departments or right holder organizers, remains in the private domain due to the commercial interests and sporting benefits of the conducting body.
- Professional motor sport teams are reluctant to allow "non-experts" to have access or interfere with their work.
- Being a high-risk sport, riders are reluctant to participate in experimental settings, especially when invasive methods are used or they fear of being exposed to something uncomfortable.
- Road race motorcycling, which includes training/testing sessions, is very expensive. No time on track can therefore be wasted, and no extra risk for crash/damage/wear is typically allowed.
- Riders report to the track from different geographical sites and are usually not available to travel extensively for laboratory evaluations.

This is not a comprehensive list, but clearly details the challenges of doing impactful research in the setting.

Stressors of motorcycle racing

In the competitive setting, the rider is exposed to a complex interaction of external and internal stresses. The inertial forces generated by the abrupt accelerations and decelerations (as well as the management of centrifugal forces), the technical movements and postures of high-speed riding (i.e. braking, cornering, changing direction, aerodynamic penetration, etc.) combined with the burden of the protective equipment (i.e. helmet, leather suit, chest and back protectors, boots, gloves, etc.), may contribute to produce considerable load to the body of these athletes. In addition, the risks and the costs of motorsports (i.e. crashes, injuries, high performance mechanical equipment, traveling, tyres, fuel, etc.), combined with the usual sporting/competition emotional and mental pressures (i.e. tension, fear, anxiety, etc.), may represent an intricate maze of the mind for the population of two-wheel racers.

Biographies of winning riders (i.e. Agostini, Rossi, Dunlop, Sheene, Lorenzo, Stoner, etc.) provide valuable first-hand experience into the riding demands, but not empirical information describing the stresses that top level competitors undergo. To better understand the human demands of motorcycle racers in a more holistic manner, the available peer reviewed literature was collated and discussed under the following section headings: Injuries and sports medicine, physiological, mechanical and psychological loads.

Injuries and sports medicine

Riding motorcycles on public roads has been a topic investigated in terms of behavioural patterns (Crundall, van Loon, Stedmon, & Crundall, 2013; Horswill & Helman, 2003; Reeder, Chalmers, & Langley, 1996) and road accidents (Day et al., 2013; Jackson & Mello, 2013; Lin & Kraus, 2009; Pai & Saleh, 2007; Stella, Cooke, & Sprivulis, 2002), but few publications have clarified details of crash-related injuries in modern road racing riders involved in competitions (Bedolla et al., 2016; Chapman & Oni, 1991; Costa, Caroli, Pagani, de Gennaro, & Guerra, 1983; Hackney, Varley, Stevens, & Green, 1993; Hinds, Allen, & Morris, 2007; Horner & O'Brien, 1986; Tomida et al., 2005; Varley et al., 1993; Zasa et al., 2016). Researchers analysing data from 278 dry races at the top-class of the Grand Prix world championship (from 1997 to 2016), reported that independent of environmental factors and speed of racing, 12 to 14% of starters experience a crash during a competition (D’Artibale, Rohan, & Cronin, 2018). Furthermore, during the 2013 season, an incidence rate of 9.7 crashes per 100 riding hours was recorded during the three American GPs, and 11.5% of crashes caused significant injuries to riders (Bedolla et al., 2016).

Statistical records and classifications of injuries have been of interest to several doctors engaged with medical teams offering service during motorcycle road racing competitions (Bedolla et al., 2016; Chapman & Oni, 1991; Costa et al., 1983; Hackney et al., 1993; Hinds et al., 2007; Horner & O'Brien, 1986; Tomida et al., 2005; Varley et al., 1993; Zasa et al., 2016). From those records (some of them including sidecar riders [Chapman & Oni, 1991; Varley et al., 1993]), it seems that skeletal fractures were the most common consequence of crashes (Bedolla et al., 2016; Chapman & Oni, 1991; Costa et al., 1983; Hackney et al., 1993; Tomida et al., 2005; Varley et al., 1993), and the limbs seem to be the most vulnerable site of injury since they are used to break falls and to protect more important parts, such as the head (Horner & O'Brien, 1986). In particular, the upper limbs (Chapman & Oni, 1991; Varley et al., 1993), with the shoulder, wrist and hand in primis (Tomida et al., 2005; Zasa et al., 2016), appeared to be the most frequently injured anatomical region. Chapman and Oni (1991) reported that 42% of injuries were occurring to the upper limbs, while Tomida et al. (2005) reported that 68% of injuries were fractures and 40% of total injuries were localized to the upper limb. Similarly, Varley et al. (1993) found that 60% of injured riders had bone fractures, 44% of those in the upper limb, and interestingly, 70% of fractured riders experienced multiple fractures.

The different methods and the variable events (circuit or open road track) used to collect the aforementioned data do not allow clarification or comparison of the relationship between participants, riding time, crashing events, and injured riders (i.e. injury incidence range 0.24-7%) (Bedolla et al., 2016; Chapman & Oni, 1991; Costa et al., 1983; Hackney et al., 1993; Hinds et al., 2007; Horner & O'Brien, 1986; Tomida et al., 2005; Varley et al., 1993; Zasa et al., 2016).

Moreover, considering the dates of some of those investigations and the technological and material advancements in protective equipment (i.e. airbag equipped leather suits, ergonomical and titanium-shield protections, composite fibre helmets, etc.), the pattern or percentages of crash-related injuries may have changed over time. However, the most detailed and current epidemiologic study reported that serious injuries (i.e. brain, spinal cord, internal chest and abdomen) at the top level of this sport are rare, but has quantified an injury rate ranging from 3.8 per 1000 race kilometres in the MotoGP™ class, to 16.9 injuries per 1000 race kilometres in the Moto3 class (Zasa et al., 2016).

Several researchers have highlighted the importance of high quality protective equipment worn by riders to minimize injuries (Hackney et al., 1993; Horner & O'Brien, 1986; Lippi et al., 2007; Tomida et al., 2005; Zasa et al., 2016), and discuss the improvements that should occur to tracks, rescue systems and regulations to increase racing safety (Leonard, Lim, Chesser, Norton, & Nolan, 2005; Lippi & Guidi, 2005; Lippi et al., 2007; Varley et al., 1993). However, no in-field data measurements have yet corroborated the efficiency of current protective equipment (i.e. airbag vs non-airbag suits), no analysis clarifies the causes of fatalities in motorcycle racing, and surprisingly, only two recent papers have mentioned the relevance that preventative behaviour such as strength training or crash-skills training could have on reducing overload syndromes and lowering the risk of skeletal injury to riders (D'Artibale et al., 2018a; Zasa et al., 2016).

Even though environmental safety apparatus such as air-fences, gravel traps or asphalt run-off areas appear to make circuits safer for riders, the fatality of Luis Salom at the 2016 Catalunya GP testifies the unpredictability of crash-dynamics, and the lack of literature demonstrating the scientific evidence on the efficiency of modern protective systems does not help to clarify the issue. Indeed, despite the quota of crashes happening per event (Bedolla et al., 2016; D'Artibale et al., 2018a; D'Artibale, Rohan et al., 2018), and the reported concussions (Bedolla et al., 2016; Zasa et al.,

2016) no paper can be found investigating side line screening and monitoring of head concussions in this sport, especially at national or non-professional levels (King, Hume, Gissane, & Clark, 2015; McCrory et al., 2017; Smith et al., 2017).

In addition to the traumas associated with crashes, riders seem to be exposed to some pathologies caused by the environmental and physical stresses consequential to racing. Noise-induced hearing loss was investigated in a population of 44 riders competing at the Grand Prix World Championship level in 1992 (McCombe & Binnington, 1994). It was suggested that the average hearing ability of Grand Prix riders (45% of the tested population) was significantly worse (below the 95th percentile) than age-matched, non-noise exposed controls (McCombe & Binnington, 1994; McCombe, Binnington, & Davis, 1995). Currently, the motorcycles and helmets available to riders are substantially different from the ones used 25 years ago, and although earplugs are not mandatory in competitions (but were regularly used by 39% of riders in the McCombe study), there is no data pertaining to hearing loss prevention practice in motorcycle racing. In addition to wind-noise and the sound-decibels generated by their own motorcycle while riding, athletes are exposed to environmental noise (i.e. pit-lane, garages, paddock) throughout the entire race events (3-4 consecutive days each). However, current knowledge regarding noise exposure, potential magnitude of subsequent pathologies, and efficacy of hearing loss protection devices in road race motorcycling competitions is unknown.

Another pathology often related to motorcycle racers is chronic exertional compartment syndrome of the forearms, improperly called “arm pump” by some. Manoeuvring the handlebars (i.e. steering, counter-steering), counteracting the inertial stresses (i.e. accelerations, decelerations), operating the throttle command, frequent and intense use of the brake and clutch levers, combined with a tight protective leather suit, expose the racers to a unique stress in the upper limbs, generating exceptional tension in the forearm region (Barrera-Ochoa et al., 2016; Brown, Wheeler, Boyd, Barnes, & Allen, 2011; D’Artibale et al., 2018a; Gondolini et al., 2018; Goubier & Saillant, 2003; Marina, Porta, Vallejo, & Angulo, 2011; Zandi & Bell, 2005). Even though researchers have investigated the neuromuscular patterns of force-fatigue models using laboratory protocols simulating the motorcyclist activity (i.e. brake lever pulling), considerable limitations may preclude the application of these findings to competitive riding effort (Marina, Rios, Torrado, Busquets, & Angulo-Barroso, 2015; Marina, Torrado, Busquets, Rios, & Angulo-Barroso, 2013; Torrado, Cabib, Morales, Valls-Sole, & Marina, 2015). Specifically, no inertial forces were involved in muscular activity in the laboratory setting, steering control was not included, the intermittent fatigue protocol was declared to not replicate the effort patterns of motorcycle racing, and throttle movements were involved only in a study with no riders (Marina et al., 2015; Marina et al., 2013; Torrado et al., 2015). While the work offers an interesting hypothesis regarding the specific use and co-activation of carpi radialis and flexor digitorum superficialis (in order to improve the precision and sensibility of braking) (Marina et al., 2013), these studies do not clarify the parameters that may be involved with the compartmental syndrome and do not provide information relating to the physiological variables associated with riding performance.

Symptoms of local pain and pressure in the forearm region, muscular tension, loss of strength and lack of grip control may occur during and after motorcycle riding (Barrera-Ochoa et al., 2016; Brown et al., 2011; Gondolini et al., 2018; Goubier & Saillant, 2003; Zandi & Bell, 2005). In pathological conditions, local pain can appear after 2 to 20 minutes of motorcycle riding (Barrera-Ochoa et al., 2016; Gondolini et al., 2018; Goubier & Saillant, 2003). Authors have suggested that treatment for forearm chronic exertional compartment syndrome is surgical decompression by a fasciotomy of all affected compartments (Barrera-Ochoa et al., 2016; Brown et al., 2011; Gondolini et al., 2018; Goubier & Saillant, 2003; Zandi & Bell, 2005). While the use of surgical interventions have proven successful in the treatment of this chronic syndrome (up to 94% of riders satisfied with the outcome) (Barrera-Ochoa et al., 2016), and riders can regain full riding capacities in a range of 1 to 5 weeks (Gondolini et al., 2018), the efficacy of non-operative treatments or preventive methods (i.e. specific muscular strengthening and stretching, regimen of myofascial tissue treatment or technical adaptations) seem relatively unexplored (D'Artibale et al., 2018a; Garcia-Mata, 2013).

Physiological load

High speed racing exposes the riders to a variety of stresses that contribute to a complex physiological load. Indeed, with the exception of endurance events, classic sprint races are fierce competitions where a multitude of riders battle and push themselves to their limits to stay in front of their opponents from the start to the end of the race, without pit stops or time-breaks of any sort (D'Artibale et al., 2007). Sprint races last from 22 to 44 minutes (national to top level) without interruption and riders compete wearing full body protective garments (Brearley, Norton, Kingsbury, & Maas, 2014; D'Artibale et al., 2018a; D'Artibale et al., 2007; D'Artibale, Rohan et al., 2018). Consequently, intense neuromuscular activity is required to ride fast and manoeuvre the motorcycle on the track while counteracting the numerous inertial stresses to which the rider is subjected (D'Artibale, 2014; D'Artibale et al., 2018a; D'Artibale et al., 2007; Filaire et al., 2007). This section explores the contributing factors to this physiological load with reference to anthropometry, cardiovascular, metabolic and hormonal physiology, as well as thermal stress and other performance limitations.

Anthropometry

The body mass and size of the racers are considered influential to riding performance (D'Artibale et al., 2018a; D'Artibale et al., 2008; Sánchez-Muñoz et al., 2011). The final mass of the rider-motorcycle affects the engine power-to-weight ratio, and consequently the ability to obtain high acceleration (reaching higher top speed before the next turn). Therefore, since motorcycles are weight-regulated, a lighter and smaller rider is usually considered favourable to final performance (D'Artibale et al., 2018a; D'Artibale et al., 2008; Sánchez-Muñoz et al., 2011). Indeed, a comparison of a cohort of 27 young elite riders (mean age 15.6 yrs.) with a reference group of Spanish physically active adolescents (mean age 16 yrs.) showed that the racers were significantly lighter (-12.5 kg), smaller (-4.7 cm), and had significantly lower values for almost all skinfolds and for all the measured girths, with unclear results in regards to the forearm (i.e. authors statement in abstract in contrast with data and results) (Sánchez-Muñoz et al., 2011). Furthermore, data from a population of 26 female national and international level riders (mean age 30.8 yrs., body mass 56.5 kg and stature 164 cm) placed the group in the low percentile (between the 10th and the 15th percentile) for body mass and at the 50th percentile for body height (D'Artibale et al., 2007; Fryar, Gu, Ogden, & Flegal, 2016). Similarly, analysis of top-level professional male riders (mean age 26.9 yrs.) found they were relatively light (63.9 kg) and in the lower percentile range of stature (172.2 cm) (D'Artibale et al., 2018a; Fryar et al., 2016). In contrast, Filaire at al. (2007) measured 12 national level riders (mean age 22.2 yrs.) and showed they had bigger body sizes (mass 76.4 kg and stature 178.4 cm).

While a small and light racer might be an advantage in the low and mid-class categories, where the power-to-weight ratio is more affected by the human portion of the total mass due to limited engine power, further research is required to validate this general assumption when racing larger, heavier and more powerful motorcycles. Indeed, a rider with longer limbs might be biomechanically advantaged in handling inertial forces associated with abrupt braking and high speed leaning when cornering (i.e. centre of mass displacement) (D'Artibale et al., 2018a). Furthermore, there may be an ideal range of body mass that supports the efficiency of the tyres, by properly loading the rubber-to-tarmac, to create the proper conditions to offer the ideal grip for intense accelerations. In conclusion, while logic suggests that generally a lighter rider should better for performance, the real influence of anthropometry on optimal performance is currently unknown.

Cardiovascular, metabolic and hormonal physiology

The physiological demands associated with road racing during official competitions have been quantified via the measurement of heart rate, concentration of blood lactate, salivary cortisol and gastrointestinal temperature (Brearley et al., 2014; D'Artibale et al., 2008; D'Artibale et al., 2007; Filaire et al., 2007). Direct measurements of heart rate and blood lactate concentrations of female and male riders during free practices, qualifying sessions, and races in official national and international circuit motorcycle racing competitions indicate that competitive riding imposes a high cardiovascular load on the riders (D'Artibale et al., 2008; D'Artibale et al., 2007; Filaire et al., 2007).

During competition, heart rates in female riders has been reported to be 77 ± 6% of its maximum value (HRmax) at the start, increasing rapidly to 92 ± 6% HRmax within the first 50 seconds, and remaining at that level until the end of the race (end heart rate: 98 ± 5% HRmax) (D'Artibale et al., 2007). Similar trends have been reported in male riders (Filaire et al., 2007), with heart rates almost always reportedly above 90% HRmax (frequency of occurrence in different categories: 125GP = 92.9 ± 5.3%; 250GP = 93.6 ± 7.3%; 600cc = 93.2 ± 10.2%) (D'Artibale et al., 2008). Interestingly, no differences have been shown between male riders who reached the podium at the end of the race (frequency of occurrence of heart rate above 90% HRmax = 92.9 ± 7.7%) and those who did not (heart rate above 90% HRmax = 93.5 ± 8.9%) (D'Artibale et al., 2008). Furthermore, in a longitudinal case study, a positive correlation (r = 0.76) was shown between the cardiac response (frequency of occurrence HRmax >90 %) and lap performance (mean speed of racing), but not between cardiac load and perceived track difficulty (D'Artibale, Tessitore, Tiberi, & Capranica, 2006).

Heart rate as a sole measure cannot differentiate between mental and physical stressors, therefore the measure of strain in motorsports must take into account the specific complexity of each performance settings (D'Artibale et al., 2007; Schwaberger, 1987). Indeed, given the psycho-emotional stress associated with high-speed motorcycle racing, additional catecholamine (i.e., adrenaline) release would be expected during such activity (Ascensão et al., 2008; Ascensão et al., 2007; Del Rosso, Abreu, Webb, Zouhal, & Boullosa, 2016; Filaire et al., 2007; Tsopanakis & Tsopanakis, 1998). While some researchers postulated that the physical demands of high-speed riding or driving are a substantial component of the elevated heart rate (Bach, Brown, Kinsey, & Ormsbee, 2015; Ceccarelli, 1999; D'Artibale et al., 2008; D'Artibale et al., 2006; D'Artibale et al., 2007; Filaire et al., 2007; Gobbi et al., 2005; Jacobs, Olvey, Johnson, & Cohn, 2002; Konttinen, Kyröläinen, & Häkkinen, 2008), others attributed the prevalence of this elevation to increased sympathetic nervous output and changes in hormone levels due to anxiety and other emotional responses (Schwaberger, 1987). Moreover, the thermal stress to which the riders can be exposed to (i.e. hot environment, hot motorcycle, protective garments, etc.) and potential dehydration might represent an additional factor contributing to increased heart rate (Brearley & Finn, 2007; Lafrenz, Wingo, Ganio, & Cureton, 2008; Walker, Ackland, & Dawson, 2001; Wingo, Ganio, & Cureton, 2012).

Hemodynamic analysis (i.e. stroke volume, cardiac output, left ventricular ejection time, etc.) has been used to further the understanding of the cardiovascular responses to off-road riding and the effect of dynamic or static muscular efforts (Sanna et al., 2017). For example, using this technique, Sanna et al. (2017) provided evidence to suggest that muscle activity during a 10-min enduro training session activates the mechano-metaboreflex, leading to a sympathetic-mediated venous constriction, and an enhanced cardiac pre-load (i.e. end diastolic volume). However, it would seem that profiling the performance of motorcycle-riding in real competitions, necessitates a more expansive multi-systemic, discipline-specific approach (Carlson, Ferguson, & Kenefick, 2014; D'Artibale et al., 2007; Del Rosso et al., 2016; Filaire et al., 2007; Gobbi et al., 2005; Jacobs et al., 2002; Konttinen et al., 2008; Potkanowicz & Mendel, 2013). Even though literature in other motorsports can offer insights into explaining the cardiovascular load in motorcycle road racing, careful consideration must be taken when relating data from car driving or off-road motorcycling to road racing, since the athletes are subject to different stresses/forces, act in different postural positions, wear different protective equipment, are subject to different environmental conditions, and move their bodies differently to operate and control their respective machines.

Direct metabolic assessment via gas analysis during motorcycle riding could assist to clarify the energetic demands of racers, but so far only a single case study has been publicly presented to the scientific community describing this with an amateur and a competitive rider (D'Artibale, Tessitore, Lupo, & Capranica, 2013). Using direct gas analysis while riding on the track during private testing, oxygen consumption was shown to be four and seven times the basal value in an amateur and competitive rider respectively; the mean speed 40% higher in the competitive rider under non-competition conditions (D'Artibale et al., 2013).

Blood lactate concentration values measured after racing have provided evidence of the high metabolic involvement required to control the motorcycle at a high speed (D'Artibale et al., 2008; D'Artibale et al., 2007; Filaire et al., 2007). Post-race sampling from international and national male racers (125GP, 250GP and 600cc class) and female riders (600cc and 1000cc class) were both very high, ranging from 5.6 to 6 ± 2.1 mmol/l for men and 4.5 ± 1 mmol/l for women (D'Artibale et al., 2008; D'Artibale et al., 2007; Filaire et al., 2007). The mean speed of racing in these measured populations ranged from a minimum of 115 km·h-1 to a maximum of 144 km·h-1, while top-level competitions during the same time period have recorded mean racing speed of 161 km·h-1 (D'Artibale, Rohan et al., 2018).

In terms of the hormonal responses to competitions, both the qualifying session and the race have been reported to induce a high level of stress on 12 male riders, characterized by an anticipatory response to the contest. Cortisol concentrations measured in the morning before the race have been shown to be up to three times higher than those measured on a resting day (Filaire et al., 2007). In fact, there was a significant progressive increase in the cortisol concentrations on the riding day, with values measured 10 min after the race being highest (57.3 ± 4 nmol·L-1 vs 13.2 ± 2 and 4.04 ± 2 nmol·L-1 as basal values). There was also a significant decrease (-48%, P<0.01) in cortisol values 60 min after the race, but the concentration was maintained at a higher level for a longer period; values reported more than 4 hrs after the end of the race were significantly higher (332%) than those reported at the same time on a resting day (Filaire et al., 2007). Such manifestations are expected, with cortisol the major stress hormone arising from the hypothalamic-pituitary-adrenal axis, indicative of the arousal state (Filaire et al., 2007).

Thermal stress and other performance limitations

Worldwide, road race motorcycling competitions are held during the warm months of the year, and typically scheduled during the central, brightest hours of the day. Factors such as the physical demands of riding, protective equipment and environmental conditions of racing (i.e. internal combustion engine between rider's legs, dark asphalt track, etc.) can all contribute to thermal stress and consequently limit the rider's performance (Brearley et al., 2014; D'Artibale et al., 2008). To quantify the physiological responses to heat, the gastrointestinal temperature of four male riders (median age 24.5 years) were measured during a national event held at high ambient temperatures

(29.5 – 30.2ºC) and elevated environmental humidity (64.5 – 68.7%). Racers' gastrointestinal temperature increased from 37.6°C in the pre-session, at a median rate of 0.035, 0.037 and 0.067°C/min during practice, qualifying and race sessions, respectively; again highlighting the considerable physical/metabolic demands of racing (Brearley et al., 2014). Peak post-session gastrointestinal temperature reached a median value of 38.9, 38.8 and 39.1°C during practice, qualifying and race sessions, respectively. Riders' thermal sensation was reported as “very hot” after each riding session, and sweat rates ranged from 1.01 to 0.90 litre/hour during practice and qualifying sessions (Brearley et al., 2014). Considering the limited permeability of racers' protective clothing, their inability to use active cooling and the environmental conditions of the track, riders clearly get hot during competitive riding. However, investigation of methods that limit the impact of thermal strain on a riders' performance, and the efficacy of pre-cooling or acclimatization strategies, are currently unpublished (Brearley et al., 2014).

Assumptions in regards to the low concentrations of CO_2 (and lowered concentrations of O_2) inside the visor-closed integral-helmet, and their effects on cognitive abilities relevant to the control of a motorcycle, have been investigated as potential problems (Brühwiler, Stämpfli, Huber, & Camenzind, 2005). Nevertheless, when moving at reasonable speed, the CO_2 concentration values inside an integral helmet equals levels associated with normal breathing; indeed, riders rarely experience breathing discomfort except when standing still, suggesting that normal road speeds are sufficient to ventilate the helmet dead space (Brühwiler et al., 2005).

Since visual performance could be considered an essential attribute for racers, it has been proposed that athletes competing in high-speed sports require superior dynamic visual acuity (Schneiders et al., 2010). Undeniably, motorsport is a dynamic reactive sport which requires sustained visual performance in the areas of contrast judgement, directional localisation, visual resolution and peripheral and far distance demands (Erickson, 2007). Indeed, motorcycle racers are required to process visual information quickly to rapidly analyse available temporal and spatial information during racing situations in order to make accurate decisions on technical maneuvers (i.e. braking markers, corner's apex, etc.). The only published study measuring gaze stabilization, visual acuity and perception time in nine male car drivers (mean age 17.6 years) reported that this limited population of motorsport athletes demonstrated superior visual acuity in the horizontal plane compared to the controls for all measures (Schneiders et al., 2010).

The complexity of systemic requirements articulated previously suggest that professional programming for riders' preparation to racing would be a prerequisite to successful performance, however, very limited studies have described the training methods of this population of athletes and no literature is available in support of specific evidence-based training practice. Indeed, both a world-wide selection of young riders (n=27, mean age 15.3 years) competing internationally in an entry-level category during the 2009 season, and a population of female riders (n=18, mean age 25.8 years, 2013 season) were reported to have a poor approach to preparation practices (Rodríguez-Pérez, Casimiro Andújar, Sánchez Muñoz, Mateo March, & Zabala Díaz, 2013; Martin, Blasco, Fargueta, Olcina & Monleon, 2015).

While 88% of international young male racers considered physical training essential to improving their performance during competitions, only 27% of them and 33% of female racers reported using a coach or trainer for programming preparation (Rodríguez-Pérez et al., 2013; Martin et al., 2015). In particular, despite the number of hours dedicated to physical training (from 6.9 to 8 hours per week) it is unclear the rationale of allocation for endurance (95% of riders run and cycle), flexibility (80% of them train range of motion), and strength training (just 74% of riders include strength training sessions, with predominant use of weight training machines, free body load and free weights) (Rodríguez-Pérez et al., 2013). The absence of specificity (i.e. instability/proprioceptive exercises, riding skills training, etc.) (Rodríguez-Pérez et al., 2013), mental and tactical training (Martin et al., 2015), as well as the trivial support of professional guidance that riders seem to be exposed to (in regards to human development) (Martin et al., 2015), are perhaps the reflection of the cultural setting in motorcycle road racing, and/or may be the consequence of the paucity of literature investigating this population of athletes. There is no doubt that a more systematic evaluation of racers preparation practices who are competing at the top-level of modern motorcycling is needed. Quantifying their physiological loads and their training regimens, would help to determine more specific solutions for the systemic component of the human side of this sport.

Mechanical load

Riding at high speed on a track with multiple bends and curves, and to record consecutive laps within a range of a few tenths of a second, requires the rider to master precise control of the tri-axial dynamics of the motorcycle (i.e. pitch, roll, and yaw for longitudinal load transfer during changes of speed, lateral leaning during cornering and steering/counter-steering for bike directionality respectively). The specific actions that riders are required to execute, and the inertial forces they are subjected to while riding, represent the mechanical load for these racers.

By operating the engine and the brakes (via the throttle, gearshift, clutch and brake levers), by manoeuvring the handlebars (i.e. steering, counter-steering) and by moving the body (i.e. aerodynamically penetrative position, braking posture, different phases of cornering, changing direction, etc.) and shifting their mass on-bike around the centre of mass of the motorcycle (i.e. along the seat, from foot peg to foot peg, hanging on tank or pushing on handlebars, etc.) (Cocco, 2005; Cossalter, 2006; D'Artibale et al., 2018a; D'Artibale et al., 2008; Evertse, 2010; Ibbot, 2013;

Marina et al., 2011; Tanelli, Corno, & Savaresi, 2014), a rider attempts to minimize his/her lap-time and finish the race in front of their opponents. To improve their performance, riders aim at increasing their mean speed throughout the lap, therefore late braking, early and intense corner exits and high mid-cornering speed are desired (D'Artibale et al., 2018a; Ibbot, 2013). These manoeuvres expose the rider to abrupt postero-anterior and antero-posterior accelerations, as well as centrifugal forces balanced by leaning the motorcycle into corners (Cocco, 2005; D'Artibale et al., 2018a; D'Artibale et al., 2008; Ibbot, 2013).

Riders at the top level (i.e. MotoGP™) are required to perform for about 43 minutes at mean speeds higher than 160 $km \cdot h^{-1}$ per lap, braking more than 170 times and leaning into the curves more than 370 times per race (D'Artibale et al., 2018a), however, the measurement of the forces associated with these actions and the consequent muscular strength involved, are currently unknown. What has been quantified at the professional level in recent years (2013-2015), is that over 40% of postero-anterior negative accelerations (braking action) were initiated at a speed higher than 260 $km \cdot h^{-1}$, 13% of these at over 300 $km \cdot h^{-1}$, and it has been reported that a braking action lasting 4.2 ± 0.6 seconds was performed every 11.6 ± 4.1 seconds of racing (D'Artibale et al., 2018a). Considering that it is expected that the decrease of speed is of a non-linear shape, it has been calculated that professional riders using top-level carbon disk brakes experience a mean negative acceleration ranging from 16.5 to 2.7 $m \cdot s^{-2}$, and 25% of those braking actions generated a mean inertial stress greater than 1g (D'Artibale et al., 2018a). While these repetitive braking actions might be considered of lower magnitude in lower categories (i.e. lower mean speed of racing and no use of carbon brake systems), and even though this sport is highly supported by forefront technology at any level, currently no published research has instrumented the motorcycle or the rider with the intent of profiling the physical stresses of competitions to quantify the relative muscular strength requirements of racing.

Only two studies have performed cross-sectional measurements of road racing riders' muscular capacities (i.e. handgrip strength, lumbar isometric strength and vertical countermovement jump) (D'Artibale et al., 2007; Sánchez-Muñoz et al., 2011). Handgrip peak strength was reported to be significantly higher in the right hand (used to operate the brake lever and gas throttle) compared to the left hand (used to operate the clutch lever) (307 N vs 281 N) in female adult riders (D'Artibale et al., 2007), and similarly, reported to be significantly higher in young elite riders: 402 N for the right-hand vs 371 N for the left hand (Sánchez-Muñoz et al., 2011). Recognizing that hypertrophic forearms seem to be a common characteristic of motorcycle riders (Bach et al., 2015; Garcia-Mata, 2013), and considering that the more specific use of the clutch lever in off-road riding demonstrated a left dominance (Gobbi et al., 2005), the load due to hard braking for road racers summed to the frequent full wrist extension to keep the throttle fully open, could explain the stronger right side and the more frequent occurrence of forearm compartmental syndrome on the same limb (Gondolini et al., 2019). Despite the evolution of technology facilitates some technical actions (i.e. clutchless electronic gearing system, electronically controlled engine brake, electronic "ride-by-wire" throttle system etc.), with the constant improvements of the motorcycle components such as braking systems, tyre compounds, suspensions and electronically controlled engine power, the physical stresses on the rider appear to be increasing in intensity (D'Artibale et al., 2018a; D'Artibale, Rohan et al., 2018; Lippi et al., 2007).

Engineering manuals (Cocco, 2005; Cossalter, 2006) and academic papers (Cossalter, Doria, Lot, & Massaro, 2011; Cossalter, Lot, & Rota, 2010; Evertse, 2010; Massaro, Lot, Cossalter, Brendelson, & Sadaukas, 2012) have been aimed at analyzing and improving the dynamics of the motorcycle and only indirectly have described general rider's actions or riding skills such as the 'optimal manoeuvre method' (Bobbo, Cossalter, Massaro, & Peretto, 2009; Cossalter, Da Lio, Lot, & Fabbri, 1999; Sharp, 2014). However, such resources do not explain the real stress on a rider because they use the concept of an ideal rider; that is, a rider that can perform any required optimal-control manoeuvre, such that the vehicle can follow the best possible trajectory and the highest performance is achieved in the manoeuvre. The optimal manoeuvre method therefore is vehicle specific, determining an optimal control sequence for each vehicle for a specific manoeuvre (Kooijman & Schwab, 2011). Those mechanical analyses of motorcycle dynamics and subsequent models of riding performance, however, do not clarify the actual demands of competition riding or the physical demands on the rider.

Psychological load

Although riding behavioural patterns and cognitive processes have been studied in relation to public road accidents and urban traffic dynamics (Babajanpour, Asghari Jafarabadi, & Sadeghi Bazargani, 2017; Cox, Beanland, & Filtness, 2017; Crundall et al., 2013; Horswill & Helman, 2003), psychological factors important to motorcycling competitions have been rarely investigated (Dosil & Garcés de Los Fayos, 2006; Mateo-March et al., 2013). Dosil and Garcés de Los Fayos (2006) reported that the psychological demands of motorcycle road racing were embedded within the specific characteristics of racing and the technical peculiarities of this high-cost sport.

In particular, control of pre-competition anxiety of varying intensity (depending on the phase and period of competition/season), and self-confidence (also in relation to the risks of this sport) are considered fundamental in a high-speed sport where a mistake can cause severe injuries to the athlete or repercussions on his/her career (D'Artibale et al., 2018a; Dosil & Garcés de Los Fayos, 2006). With regards to experimental research, a program of physical, technical and tactical training has been implemented previously and appeared to have unclear effects on the psychological status of young elite riders (mean age 15.6 yrs.) (Mateo-March et al., 2013). Following a 2.5-month period of physical conditioning, riding practice and tactical training, experts using subjective evaluations of technical execution, physical efficiency and psychological response to competitions indicated improvements in technical, physical and psychological status in the experimental group (n=16). This was confirmed by a better index of performance given by results in ranking positions and championship points. While the PSS-10 perceived stress scale indicated lower values in the riders following the experimental training program, no significant differences were reported in self-evaluated physical and psychological status, and also self-esteem (measured through a 10-item Rosenberg scale) was not different between the experimental and control group (n=11) at the end of the intervention program (Mateo-March et al., 2013).

The ability to concentrate and focus attention on the several aspects of the riding performance (such as the front/rear load of the motorcycle, the engine RPM, the gears, the leaning angle, the opponent lines, etc.), and the use of imagery have been declared to be some of the psychological skills utilized by racers (Dosil & Garcés de Los Fayos, 2006); however, there is a lack of literature measuring the effects of these skills on racing performance. Psychological support through interventions consisting of a combination of relaxation techniques, imagery, positive self-talk and affirmations, goal setting, negative thought stopping and cognitive restructuring were reported to be successful (all of the 12 self-measured constructs showed positive changes) in a case study with an injured national level rider (Jevon & O'Donovan, 2000). In this intervention program, Jevon & O'Donovan (2000) used a variation of "Butler's performance profile" over 12 weekly appointments to monitor the development of psychological factors assessed to be important to the recovery of a seriously injured motorcycle racer.

For success, riders are also required to master emotional self-control (to minimize mistakes and risks) and decision-making (to discriminate decisions and prioritize actions), as well as possess communication skills (interactions with their team, media and sponsors) and establish and manage objectives successfully (short, medium and long term goals in different areas directly or indirectly related to performance) (Dosil & Garcés de Los Fayos, 2006). The personality construct of hardiness, which is a personality characteristic anticipated to explain the differences in mood states among individuals who are subjected to stress, appears to be an important component in the success of a rider since it was found to be significantly higher in professional riders when compared with club racers (Thomas, Reeves, & Agombar, 2013).

Interestingly, since the effect of physical, technical and tactical training related to motorcycling has been reported to lower the perceived stress in young elite riders (Mateo-March et al., 2013), and physical training seems to decrease the strain of human beings during psycho-emotional-concentrative stress situations (Schwaberger, 1987), no information is available in regards to the age, experience or training loads/habits of the professional riders with a higher hardiness score (Thomas et al., 2013). Therefore, the interaction between age, level of performance, training habits and the effects of psychological training, would appear unanswered at this point in time.

Despite the psychological attributes of a rider being reported to be significantly influential in riding performance (Dosil & Garcés de Los Fayos, 2006; Jevon & O'Donovan, 2000; Mateo-March et al., 2013; Thomas et al., 2013), very few publications have investigated the rider within this context, and only few riders (i.e. higher levels) seem to be regularly supported by a sport psychologist or have a structured approach to improve their mental performance (Dosil & Garcés de Los Fayos, 2006; Jevon & O'Donovan, 2000; Martin et al., 2015; Thomas et al., 2013). Beside anecdotal references of riders' “mind games” (Bayliss & Trevitt, 2014; Ibbot, 2013; Rossi, 2006; Stoner, 2014), psychological skills and mental strategies used by riders in competitions, qualifying or free practice are seemingly undefined. More importantly, a well-rounded psychological profile of successful motorcycle racers and the effects of an experimental protocol of mental skills training on rider's performance would benefit understanding in this area substantially.

Conclusion

The limited work that has been completed to date suggests that the human performance in motorcycle circuit racing involves a complex interaction of specific skills and abilities. High performance riders are exposed to physiological, mechanical, and psychological stresses, in addition to potential injuries due to crashes or localised muscular overload (i.e. chronic exertional compartmental syndrome of the forearm). From the literature, riders involved in competitions are recommended to possess proper levels of body composition, cardiovascular fitness, muscular strength, specific flexibility and heat tolerance. Furthermore, specific resistance to inertial stresses, visual acuity, mental and physical resilience, psychological strategies and behavioural awareness along with technical riding skills appear to be meaningful to perform successfully.

Recommendations

Riders may benefit from specific multidisciplinary training to minimize the effects of fatigue during competition, to prevent risks of injuries, to improve their technical and mental skill set and capacities, and to manage successfully their investments towards their racing career. Considering the risks, costs and specificity of motorcycle circuit racing, both young and adults riders are recommended to be guided and assisted by highly specialised professionals that take a holistic approach to improving their performance.

Future research

From this review, it is evident that further work is needed to profile riders according to their level and to demonstrate how best prepare them by creating evidence-based methodologies and model-of-performance-based training protocols that improve their performance in competitions. Undoubtedly, future research should be aimed at improving safety for these populations of athletes, by means of measuring the effects of technological (i.e. equipment, facilities, etc.) and behavioural solutions (i.e. regulations, crash-skills techniques).

Physiological, psychological and biomechanical investigations are recommended to deepen our understanding into the magnitude of metabolic, mental, technical and muscular demands in relation to the anthropometric characteristics, categories of competition and success rate. The influence of the human component on final performance is currently understudied and the potential benefits of investing in human aspects to improve racing performance needs to be considered. Furthermore, the under-representation as well as biased beliefs pertaining to female involvement and racing ability (in a male-dominated sport) needs exploration (Brown & Yang, 2015). Future research is needed to evolve the cultural resistance prevalent in motorcycle racing and to invest in riders, by providing evidence-based applications that improve rider performance. This information should not be viewed in isolation but rather in tandem with current experience-based practices.

Chapter 3 – Trend analysis of 20 years of FIM road racing Grand Prix motorcycle world championship.

This chapter comprises the following publication in *International Journal of Sports Physiology and Performance.*

Reference:

D'Artibale, E., Rohan, M., Cronin, J.B. (2018). Trend analysis of 20 years of FIM road racing Gran Prix motorcycle world championship. *International Journal of Sports Physiology and Performance, 13*(6), 795-801. doi: 10.1123/ijspp.2017-0664

Author contribution: D'Artibale E: 87%; Rohan M: 8%; Cronin J: 5%

Prelude

In Chapter 2, the available scientific information in regards to the human performance in motorcycle circuit racing was reviewed, which allowed the identification of the gaps and limitations in the literature. One limitation that was identified was that there was no literature describing the basic characteristics of the sport and if any changes (e.g. magnitude of racing speed) had occurred over the years. So, this third chapter was designed to define the parameters characterising the top-level of the sport, so as to establish a benchmark describing professional performances. More specifically, the purposes were to analyse and describe if the performance characteristics of the top-class of the FIM Grand Prix motorcycle world championship had changed over the last two decades, and to quantify potential interactions between race data (i.e. crashes, speed, environmental conditions, etc.). This study aims at providing a better understanding of the top class of motorcycle circuit racing, so as to inform performance-related strategies, future regulations and safety procedures.

Introduction

Motorcycle road racing competitions are considered a high-risk sporting activity (Lippi et al., 2007; Makalesi, 2014; Pedersen, 1997; Tomida et al., 2005), that is popular world-wide (Dorna WSBK Organization, 2017; MotoGP™, 2015) and is regulated by the Fédération Internationale de Motocyclisme (FIM) which supervises international championships since 1949. The considerable racing budgets and marketing interests of manufacturers in this motorsport enable improvement in the technical components of performance. Indeed, mechanical and electronic engineering, aerodynamics and materials development (i.e. tyres and brakes) have ensured the evolution of motorcycle performance (Corno, Savaresi, Tanelli, & Fabbri, 2008; Cossalter, Lot, & Massaro, 2011; Giani, Tanelli, Savaresi, & Santucci, 2013; Masi, Toffolo, & Antonello, 2010; Tanelli et al., 2014; Van Dijck, 2015). Evidence of this evolution can be observed in top level performances where circuit racing top-speed of 356.4 $km{\cdot}h^{-1}$ and open-road racing lap mean speed of 217.9 $km{\cdot}h^{-1}$ have been recorded in 2018 (Isle of Man TT, 2018; MotoGP™, 2018). Despite the current level of high-speed performances, there is only one recent scientific publication describing some characteristics and short-term changes (e.g. magnitude of speed across three years) of motorcycle circuit racing competitions (D'Artibale et al., 2018a).

The level of safety of motorcycle racers have been investigated through statistical records and classifications of injuries by doctors engaged with medical teams offering service during circuit and open-road competitions (Chapman & Oni, 1991; Costa et al., 1983; Hackney et al., 1993; Hinds et al., 2007; Horner & O'Brien, 1986; Tomida et al., 2005; Varley et al., 1993). Periodical changes in technical regulations (Lippi et al., 2007; FIM, 2018), evolution of protective equipment (Bellati, Cossalter, Lot, & Ambrogi, 2006; Boubezoul, Espie, Larnaudie, & Bouaziz, 2013; Cossalter, Aguggiaro, Debus, Bellati, & Ambrogi, 2007), and improvements in circuit safety standards (i.e. gravel traps, tarmac run-offs, air-fences, etc.), have aimed at increasing the safety in this population of athletes, however no study has elucidated the current level of risk in this sport discipline and factors related to crashes in circuit competitions.

Given the aforementioned limitations the purposes of this study are to: 1) analyse and describe how the performance characteristics of the top-class of the FIM Grand Prix motorcycle world championship (GPWC) have changed over the last 20 years; and, 2) quantify potential interactions between race data (i.e. crashes, speed, environmental conditions, etc.). Our aim is to better understand top class motorcycle circuit racing, so as to inform future regulations, performance-related strategies and safety procedures.

Methods

Methodological approach

Yearly, the GPWC is organized in multiple events, namely Grand Prix (GP), performed over several months on different tracks located around the world. A longitudinal observational research design was used in this study, where performance variables (i.e. speed of the fastest racers, starting position of the winner, crashes, etc.) and event-related data (i.e. environmental conditions, participants, etc.) of top-class world championship races (i.e. 500GP™ and MotoGP™) were analysed over twenty consecutive seasons (i.e. 1997 - 2016).

Data Sample

From the first GP of 1997 until the last GP of 2016, data from the top class of the GPWC were collected and collated for analysis. Every five years during this time period, motorcycle engine size of the top class was changed: from 1997 to 2001, 500cc two-stroke engines; from 2002 to 2006, 990cc four-stroke engines; from 2007 to 2011, 800cc four-stroke engines; and from 2012 to 2016, 1000cc four-stroke engines. Even though the research design involved the analysis of publicly available performance data, the institutional ethics review board had approved this study.

Data Source

Performance and event-related data were retrieved from: a) official Race Direction (RD) reports published on the official open-access website of the FIM Grand Prix World Championship (i.e. www.motogp.com); and, b) the official published guide of results (Haefliger, 2016).

Performance Data

For each GP, the following quantitative and qualitative variables were selected: date of event; class according to current regulations [500cc, 990cc, 800cc or 1000cc]; name of the track where GP was held; length of the track [m]; number of laps needed to complete the race; number of riders at the start of the race; number of riders crossing the finish line under the chequered flag; number of riders crashed during the race; time needed for the winner to complete the race [s]; time needed for the rider finishing in 10th position to complete the race [s]; name of the winner; starting position of the winner on the grid; time gap between winner and 2nd placed rider [s]; status of the last rider crossing the finish line under the chequered flag [unlapped/lapped]; race conditions as declared from RD at the start of the race [dry/wet]; air temperature [°C]; humidity [%]; and, ground temperature [°C].

In a racing tournament, riders collect points according to their final position at each event. According to the FIM road racing regulations, only the first fifteen riders crossing the finish line are awarded championship points in an exponentially decreasing order. In competitions, although the leading rider or group of riders are looked upon as the reference performance for setting the pace of the races, the top ten finishers are usually considered the most competitive athletes in each category or level of competition. Focusing exclusively on the performance of the race winner, especially when a talented rider with a fast bike is synonymous with victory, would restrict the analysis of performances to single machinery-rider binomials, while considering all the finishers, would include the analysis of novice participants or less competitive riders, which would not be representative of the top level of the competition (D'Artibale et al., 2018a). Therefore, in this study, to measure racing performances, the mean race duration - therefore the mean speed - between the first and the 10th rider have been considered for analysis, which are the top two thirds of the finishers being awarded championship points.

From the aforementioned selected variables, the following values were calculated: length of the GP [m]; mean race duration [s] and mean speed (MS) [$km{\cdot}h^{-1}$] between the winner and the 10th rider at the chequered flag; time gap [s] between the winner and the 10th rider at the chequered flag; percentage of riders crashing at each race in relation to number of starters [%].

Inclusion Criteria

At the GPWC, all races are categorised as either wet or dry by RD before the start of the race. The purpose of this classification is to indicate to riders the varying climatic conditions during a race, which affects their choice of tyres and the overall performance. Across the twenty years of reviewed data, regulations regarding changing weather conditions differed, from temporary interruption of the race to allowing the riders to change their bike by entering the pit lane during the race (i.e. white flag rule).

As per D'Artibale et al. (2018a), to standardize the fundamental conditions for performance-related data analysis, the following three criteria needed to be satisfied for the GPs to be included in the analysis: 1) the race was declared dry by RD before the start; 2) in case the white flag was waved at any point during the GP, none of the first ten riders crossing the finish line entered the pit lane during the race; and, 3) the first ten riders crossing the finish line completed the required original number of laps announced for the event in accordance to the official regulations in a single race.

Data Handling

Selected data were entered in a purpose-built file on Epidata Software (Lauritsen JM., EpiData Association, Odense Denmark), a software used for simple or programmed data entry and documentation with error detection features; in addition, a cross-checked system between two investigators ensured accuracy. When collection was completed, data were exported into an open source electronic spread sheet (Open Office 4.1.2).

Statistical Analysis

Descriptive statistics (i.e. mean, standard deviation, range) were used to summarise quantitative variables. The estimation of the uncertainty of the true mean (i.e. 95% confidence limits (CI)) for selected variables was calculated. To test the influence of the variables "year" and "class" on the quantitative outcome MS, a mixed model analysis was used to address the repeated events on the same circuit, and normality of data was tested with Shapiro-Wilk test. Spearman's rank correlation (r) was used to test potential relationships between variables (i.e. crashes and environmental conditions, riders starting the race, speed of racing). In addition, the percentage of victories with respect to starting position was calculated. Statistical significance was defined as p-value < 0.05. Software R version 3.3.1 was used to perform the statistical tests.

Results

From 1997 to 2016, a total of 338 GPs were held at the GPWC; 278 (82.2 %) of which satisfied the inclusion criteria and were analysed to describe changes and relationships across the competitive seasons (Table 3.1). In terms of the excluded races, four were interrupted due to crashes endangering the event (1.18 %) and 53 were affected by rain or wet tarmac (15.7 %). Data pertaining to crashes and environmental conditions were not available for the 1997 season.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Top class engine size	500cc two-stroke					990cc four-stroke					800cc four-stroke					1000cc four-stroke				
GP per season	15	14	16	16	16	16	16	16	17	17	18	18	17	18	18	18	18	18	18	18
GP meeting including criteria	14	14	14	11	12	12	14	14	13	15	15	15	13	17	13	14	16	15	15	12
Sample size	65					68					73					72				

Table 3.1. Data sample overview.

Trend of racing speed

In dry conditions, for the top ten riders a competition lasted (mean ± SD) 44 minutes15 seconds ± 1 minute 59 seconds (CI: 44'01” to 44'29”), and the MS of racing ranged from a minimum of 141 $km{\cdot}h^{-1}$ (GP of Germany 1998, class 500cc) to a maximum of 181 $km{\cdot}h^{-1}$ (GP of Austria 2016, class 1000cc). Across time, the MS increased by 1.65%, 0.63 % and 1.64 %, from 500cc to 990cc class, from 990cc to 800cc class and from 800cc to 1000cc class respectively (Table 3.2). Following the Shapiro-Wilk test, it was apparent that MS in log scale was normally distributed (p-value > 0.05). The linear mixed model analysis has shown that MS was significantly increased over the years (p-value < 0.0001) and significant changes in MS were found with class size (p-value < 0.0001) (Figure 3.1). When comparing the MS of the 500cc class with the most recent 1000cc class, an increase of 3.98 % was observed.

The mean gap between the winner and the second placed rider was 3.41 ± 3.37 sec (CI: 3.01 to 3.81), while the gap between the winner and the tenth placed was 41.1 ± 14.7 sec (CI: 39.4 to 42.9). At least one of the racers had been lapped before the chequered flag in 52.2% of the GPs under analysis (Table 3.2).

	500cc class Mean ± SD 95% CI	990cc class Mean ± SD 95% CI	800cc class Mean ± SD 95% CI	1000cc class Mean ± SD 95% CI
Riders starting per GP	22.7 ± 1.63 22.3 – 23.1	21.3 ± 2.30 20.8 – 21.9	17.5 ± 1.29 17.2 – 17.8	22.7 ± 1.88 22.3 – 23.2
Riders finishing per GP	17.1 ± 2.25 16.6 – 17.7	17.2 ± 2.26 16.6 – 17.7	14.9 ± 1.77 14.5 – 15.4	18.4 ± 2.42 17.9 – 19
% of starters crashing per GP	12.7 ± 8.30 10.3 – 15.0	12.2 ± 9.06 10.0 – 14.4	12.3 ± 8.37 10.3 – 14.2	13.5 ± 8.34 11.5 – 15.4
Mean speed top10 (km h^{-1})	157 ± 7.69 155 – 159	160 ± 6.89 158 – 161	161 ± 6.41 159 – 162	163 ± 6.87 162 – 165
Gap 1st - 2nd rider (sec)	3.34 ± 4.16 2.31 – 4.37	2.32 ± 2.19 1.79 – 2.85	4.78 ± 3.53 3.95 – 5.60	3.11 ± 2.88 2.43 – 3.78
Gap 1st - 10th rider (sec)	39.4 ± 16.9 35.2 – 43.6	39.1 ± 15.0 35.4 – 42.7	41.5 ± 12.1 38.7 – 44.3	44.2 ± 14.2 40.8 – 47.5
% of winners starting from positions 1-2-3 in the grid	75.4	79.4	82.2	81.9
Different GP-winners	12	12	5	7
% GP with lapped riders	78.5	63.2	24.7	45.8

Table 3.2. Performance-related variables of dry races in the four different top classes at the FIM Grand Prix motorcycle world championship from 1997 to 2016.

Crash rate

While a mean of 21 ± 2.8 riders started each GP (CI: 20.7 to 21.4), 12.7 ± 8.5 % of them suffered a crash per race (CI: 11.6 to 13.7); a crashing event happening every 44.6 km of racing. When considering those re-joining the race and participants retiring for mechanical issues, 16.9 ± 2.5 riders finished each GP (CI: 16.6 to 17.2). No significant association was found between crashes and MS (r = -0.07; p-value = 0.09). Neither environmental conditions such as ground temperature (r = 0.11; p-value = 0.08), air temperature (r = 0.11; p-value = 0.08) and air humidity (r = 0.03; p-value = 0.58) were associated with crash counts.

Over the 20 years of racing that were analysed, two riders suffered fatal injuries following a crash during a GP in the top class of the GPWC. Considering that 5844 participants started the 82.2% of races meeting the inclusion criteria, it can be estimated that the fatality rate from 1997 to 2016 was 0.028%.

Starting position and victories

Race winners started from pole position 46.8% of the time, while 21.9% of them succeeded starting from the second spot on the grid. A rider positioned in the first row at the starting grid (spot 1 to 4 before year 2004, and 1 to 3 afterwards) won 82.4% of dry events (Figure 3.2). In the 145 dry competitions of the 800cc and 1000cc classes, 8 different riders shared those victories, with 3 of them winning a singular race. Therefore, in the last ten years, 5 riders won 97.9% of the dry races at the GPWC.

Discussion

Following the changes in regulation (i.e. from 500cc two-stroke to 1000cc four-stroke engines) and the technological advancements occurring in the last twenty years of the FIM Grand Prix world championship, this study was aimed at providing evidence to better inform future regulations, performance-related strategies and safety procedures.

Speed of racing

Across the four “five-year eras” of racing, the trend analysis showed an increase in the mean speed of the top 10 riders leading the competitions, meaning that the races became significantly faster over time and with class changes (Figure 3.1). This phenomenon is particularly clear when the MS is longitudinally visualised in those circuits that kept the layout unchanged over the 20 years (Figure 3.3).

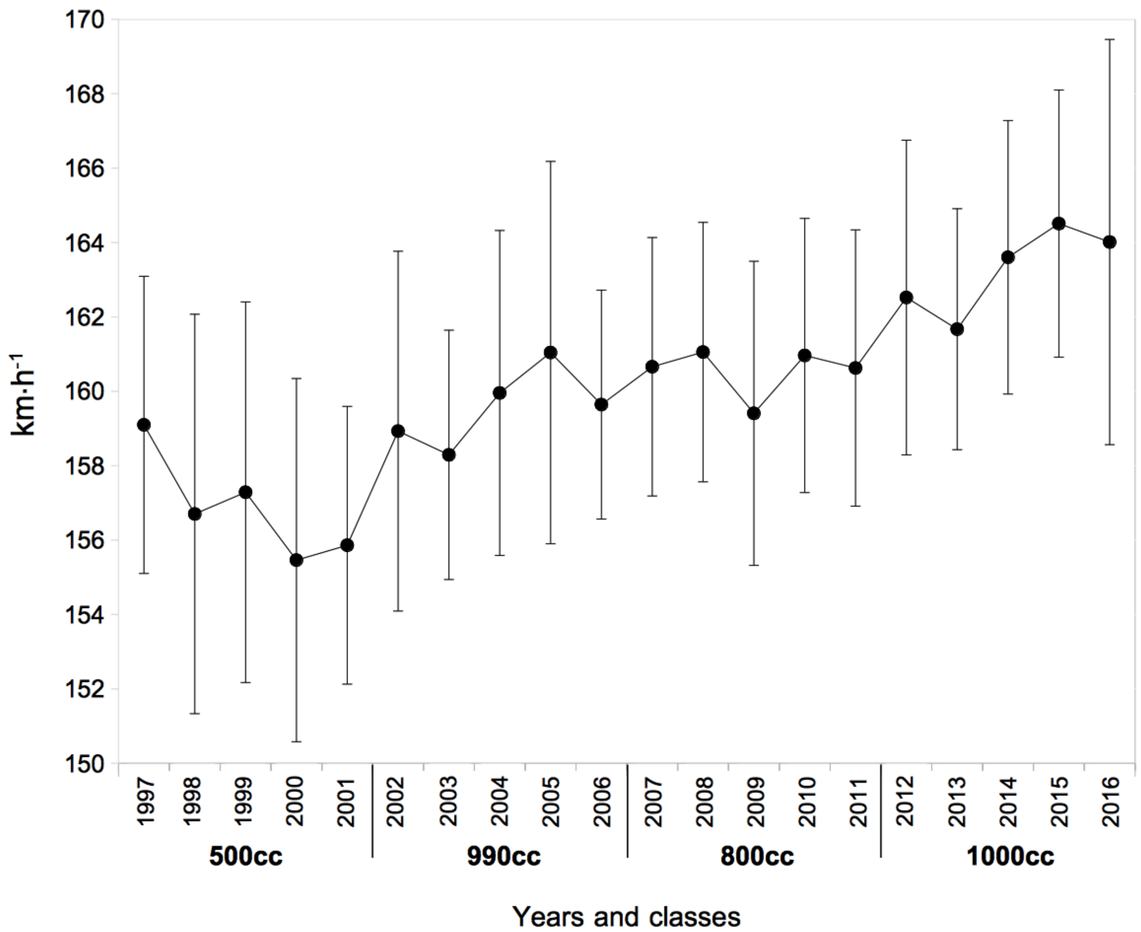

Figure 3.1. Annual means and 95% confidence interval of top 10 riders mean speed of dry racing at the FIM GP motorcycle world championship.

While the gap between the winner and the second rider slightly decreased from the oldest 500cc class (3.3 ± 4.2 sec; CI: 2.3 to 4.4 sec) to the most recent 1000cc class (3.1 ± 2.9 sec; CI: 2.4 to 3.8 sec), the gap between the winner and the 10th placed slightly increased (from 39.4 ± 16.9 sec to 44.2 ± 14.2 sec). Also, considering that the number of starters and finishers remained similar over time (with the exception of the 800cc class), the races with lapped riders decreased (from 78.5% of 500cc class to 45.8% of 1000cc class) with the criteria of track and race lengths unchanged. It can be assumed that regulations, admission criteria and supplied technological material decreased the performance gap between the faster and the slower riders competing at the top level of racing.

However, the reduced limited number of different riders winning a dry race (from 20 different names of winners in the 500cc and 990cc classes combined to 8 in the 800cc and 1000cc classes combined) and the increasing gap between the top 10 finishers may suggest that in the most recent years it has been difficult to challenge a minority of faster riders. Sharper performances and more levelled racing can be considered vital strategies in motorsports, which are aimed at maintaining high-level entertainment and top-end commercial interest. Beside the consideration that talented riders might affect results of racing, future research could clarify if this performance fracture between the top-level racers can be associated with riding official manufacturer-supported motorcycles or satellite team machines.

Similarly, the chances of winning a dry race starting from an unprivileged position seem to be slightly decreasing over the years (Figure 3.2). However, the front row starters won the race in more than 80% of the occasions constantly across the four classes.

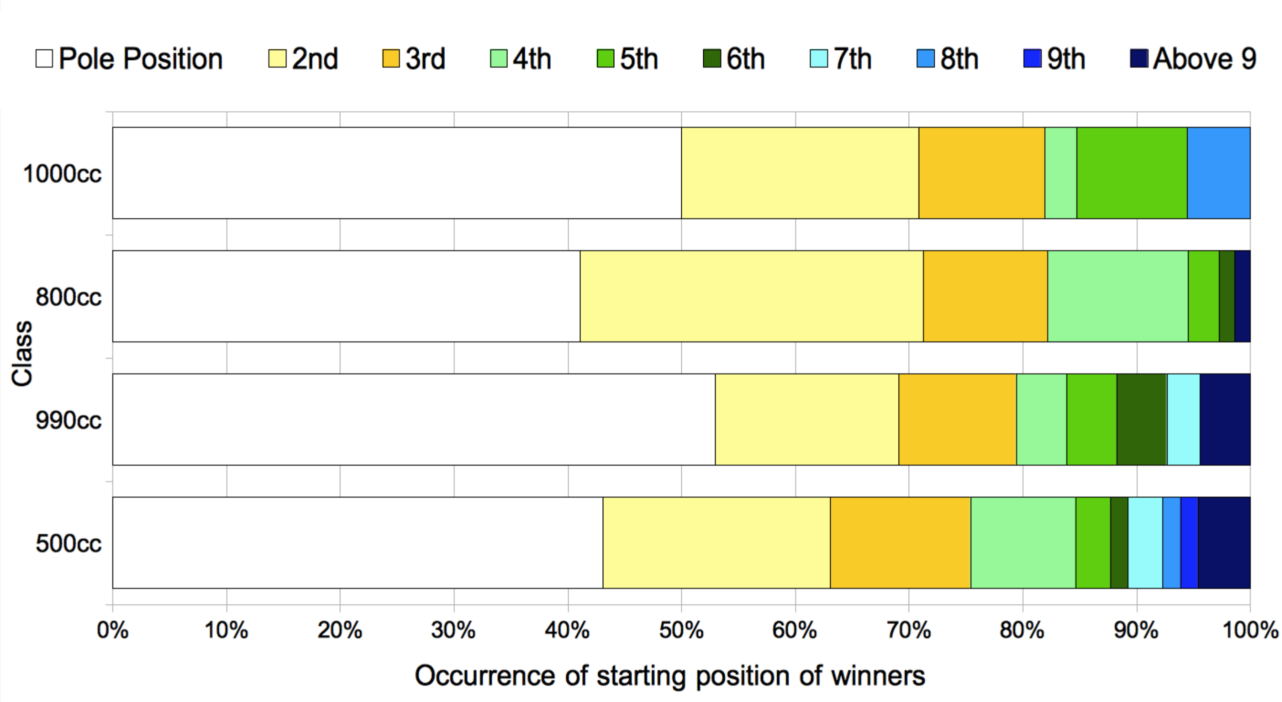

Figure 3.2. Occurrence of starting grid position of race winners at the FIM GP world championship from 1997 to 2016, divided by class.

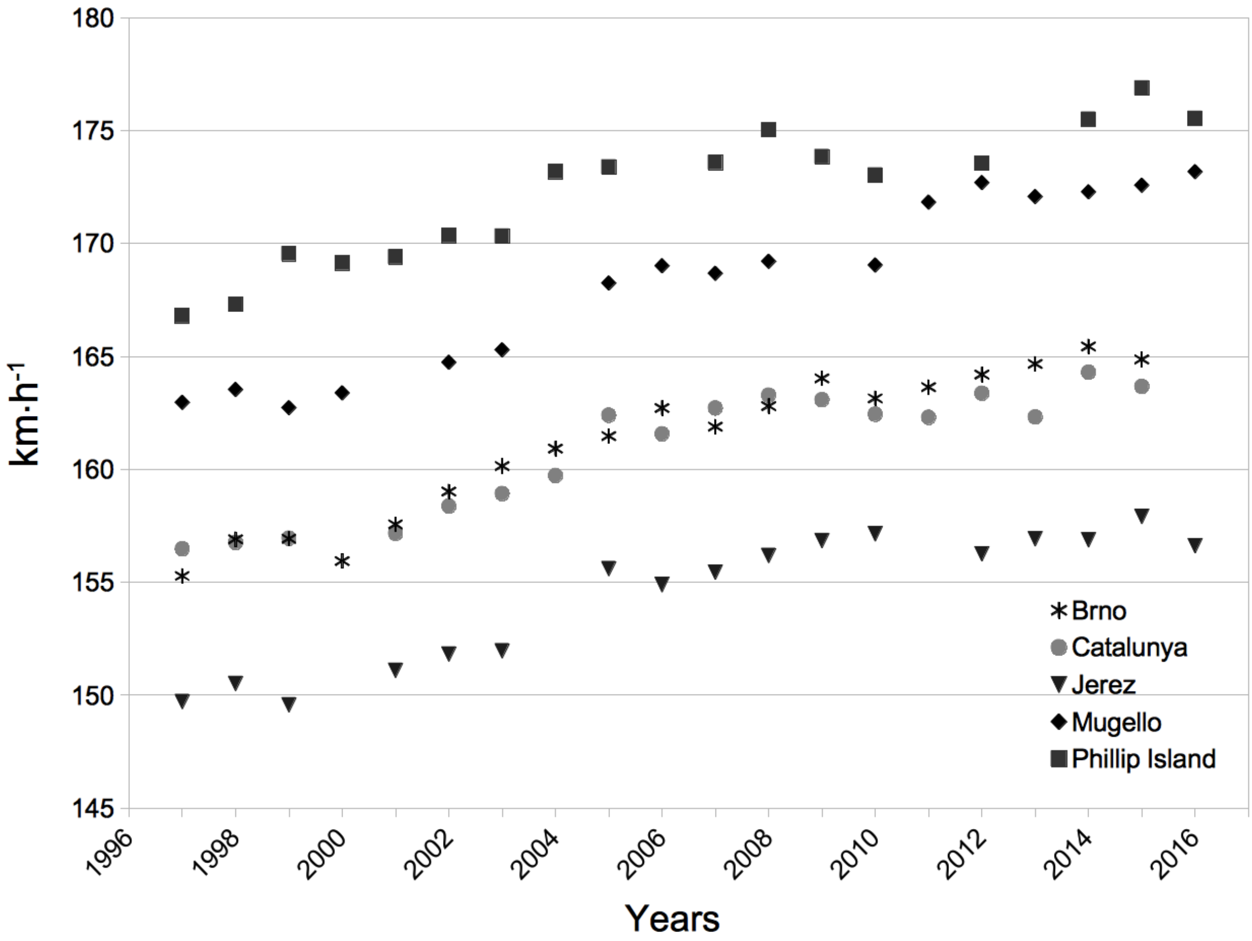

Figure 3.3. Annual mean speed of top 10 riders in a 20-year span at 5 different circuits.

Crashing as part of racing

Despite motorcycle racing being classified as a high-risk sport, little data has been published quantifying crashing events (D'Artibale et al., 2018a). From the crash data of this study, athletes competing in the sport of motorcycle circuit racing should consider the importance of being prepared to cope with such events to minimise chances of injuries given that: a) at the top level of motorcycle circuit racing, about 13% of starters have suffered a crash during a dry race; b) crashing events have not been found related to the speed of dry racing nor to dry environmental conditions (i.e. air and ground temperatures, humidity); and, c) in a twenty year span, 16% of international competitions were raced in wet conditions, where reduced ground temperature, asphalt adhesion, and visibility usually increase the crashing events.

The dynamics of motorcycle crashes can be considered unpredictable (i.e. collision with others) and the different methods and the variable events (track and open road circuit) used in the literature do not allow a clearly defined injury incidence (range 0.24-7%) (Chapman & Oni, 1991; Costa et al., 1983; Horner & O'Brien, 1986; Tomida et al., 2005). However, future research might support the design of motorcycling-specific injury-prevention crash-skills training programs for riders, which paired with the newest air-bag equipped leather suit, could lead to career and safety enhancements during competitions.

Practical Applications

From 1997 to 2016, the speed of dry racing of the top-class of the FIM Grand Prix motorcycle world championship has increased (+4%). Focusing on the human components of racing, faster motorcycles generate higher mechanical and inertial stresses (i.e. external forces), which may increase the muscular (i.e. internal forces) and metabolic demands of professional riding (D’Artibale et al., 2018a; D’Artibale et al., 2008; Filaire et al., 2007; Marina et al., 2011).

Riders starting from pole position won less than 50% of dry races and the racers placed behind the first row at the starting grid won 17.6% of world level competitions. While disparities between motorcycles should always be minimised, regulations on starting grid (i.e. new grid-shuffling system introduced at Race 2 in 2017 at the FIM World Superbike Championship) might stimulate the variability of winners, and enhance the show by challenging individual long-time supremacies.

Independent of environmental factors and speed of racing, 12 to 14% of riders starting a dry race crashed. Currently there is no evidence of specific injury-prevention training protocols available to circuit racing riders (i.e. tumbling techniques). Athletes in this sport are exposed to crashes, injuries and occasionally fatal accidents (Chapman & Oni, 1991; Costa et al., 1983; D'Artibale et al., 2018a; Hackney et al., 1993; Hinds et al., 2007; Horner & O'Brien, 1986; Tomida et al., 2005; Varley et al., 1993), therefore future research could focus on solutions to minimise the risks of this population.

Conclusions

This study provides a description of racing performance at the top level of motorcycle circuit racing. While organizers aim to improve safety and popularity of the sport as a spectacle by changing regulations, no publication has investigated the longitudinal effects of these changes. Despite this analysis being limited to the top class of prototype racing, and generalization of results to other categories requires careful consideration, this paper provides unique insight into the increasing speed of this sport, quantifying the number of crashes and offering other insights into the characteristics of winning performances.

Technological advancements in racing motorcycles make the competitions faster, consequently the increasing inertial stresses and forces of competitive riding may represent a physical load requiring adequate and specific physical preparation from riders (D'Artibale et al., 2018a; D'Artibale et al., 2008; Filaire et al., 2007; Marina et al., 2011).

Considering the frequency of crashes and the potential repercussions of injuries on a rider's career, it would seem beneficial to include a crash-skills program in the preparation plan of riders, aimed at minimising the chance of injuries during these unwanted events.

Chapter 4 – Profiling the physical load on riders of top-level motorcycle circuit racing.

This chapter comprises the following publication in *Journal of Sports Sciences.*

Reference:

D'Artibale, E., Laursen, P., & Cronin, J. (2018). Profiling the physical load on riders of top-level motorcycle circuit racing. *Journal of Sports Sciences, 36*(9), 1061-1067.

doi: 10.1080/02640414.2017.1355064

Author contribution: D'Artibale E: 90%; Laursen P: 5%; Cronin J: 5%

Prelude

With the first two studies, a contextual framework has been established and some new information was provided through a longitudinal analysis of performance-related variables in the realm of top-level motorcycle circuit racing. Races at the pinnacle of the sport have become significantly faster over time, and despite this observation may seem obvious in a speed-based sport, the previous chapter is the only publication offering a data-driven analysis quantifying a trend that may bring considerable implications to the performance of riders. In addition to the number of crashes that were highlighted, suggesting the necessity to consider such events as a reality for these athletes, faster racing also implies that riders experience greater mechanical stress/load. It was thought important to describe these stresses/loads in order to define benchmarks in support of the creation of a performance model for riders. Data from the top-level competitions was considered vital for the determination of such loads and benchmarks, therefore, quantifying the kinematics and physical stress experienced by riders throughout top-level races was considered an important investigation to undertake and provides the focus of this chapter.

Introduction

Road race motorcycle competitions are performed on asphalt tracks, take place in a wide variety of forms (i.e. on circuit or open roads, sprint or endurance races, classic or modern vehicles, etc.), are usually organized according to engine size and can be held across local club events to world level tournaments. The FIM (Fédération Internationale de Motocyclisme, officially recognised by the International Olympic Committee) established a road-race World Championship in 1949, which currently represents the oldest international motorsport tournament and the highest level of powered two-wheel prototype racing.

Technological advancements in mechanical and electronic engineering, aerodynamics and materials (i.e. tyres, brakes, tarmac) have ensured the evolution of motorcycle performance (Masi et al., 2010; Tanelli et al., 2014). Furthermore, in a high-risk sport, where crashes affect the performance outcome and potential injuries might influence a rider's career, such innovation can be observed across areas of improved protective gear and safety for the riders (Buobezoul et al., 2013; Cossalter et al., 2007). Although performance in competition depends upon the characteristics of the motorcycle and the capability of the rider, manufacturers and suppliers seem to invest exclusively in the machines, while human factors in racing may be less investigated (D’Artibale et al., 2008; Sánchez Muñoz et al., 2011), and the influence of physiological and psychological components on race outcome is largely unknown (Brearley et al., 2014; Dosil & Garcés de Los Fayos, 2006).

The intense neuromuscular activity required to ride fast and manoeuvre the motorcycle on the track (i.e. operational movements on handlebars, foot pegs and body positions) while counteracting the numerous accelerations (i.e. anterior, posterior, lateral) to which the rider is subjected (D’Artibale, 2014; Marina et al., 2011; Marina, Rios, Torrado, Busquets, & Angulo-Barroso, 2014), alongside the psycho-emotional stress associated with racing (Ascensão et al., 2007; Thomas et al., 2013), imply that motorcycle road racing imposes high mental and physical loads on the riders. The physiological demands associated with road racing during national and international official competitions have been quantified via the direct measurement of heart rate and blood lactate concentration (D'Artibale et al., 2007; D'Artibale et al., 2008; Filaire et al., 2007), salivary cortisol (Filaire et al., 2007) and gastrointestinal temperature (Brearley et al., 2014). In regards to riders' muscular capacities, cross-sectional measurements of female (i.e. handgrip) (D'Artibale et al., 2007) and young riders (i.e. handgrip, lumbar and vertical jump) (Sánchez Muñoz et al., 2011) have been published, and forearm muscle fatigue has been monitored (Marina et al., 2011; Marina et al., 2014). Furthermore, preparation practices have been investigated within limited populations (Martin, et al., 2015; Rodríguez Pérez et al., 2013); consequently, the mechanical demands of top level performance remain for the most part unstudied.

Top-class circuit racing prototype motorcycles are currently machines of 160 kg, powered by engines generating about 245 bhp, often reaching a track speed above 340 $km \cdot h^{-1}$. A world level event takes place over three or four consecutive days, with the first two or three days dedicated to practices and qualifications, whilst on the last day a warm-up session and a no-pit-stop race are scheduled (FIM, 2016). Repeated movements and high intensity braking actions are technical manoeuvres influencing individual performance and exposing the riders to substantial physical stress (Barrera-Ochoa et al., 2016; Goubier & Saillant, 2003; Marina et al., 2014), however only few studies have analysed the physical load experienced by professional riders and no publications have information pertaining to crashing events in circuit racing motorcycling.

As technology in the sport sciences is rapidly evolving, and riders are encouraged to push themselves and their machines to their limits, further investigation into the technical, physical and tactical aspects of a rider's performance is needed to understand motorcycle racing preparation and performance. The aims of this study were to quantify the physical stress experienced by riders by analysing race results alongside kinematic data from top-class circuit racing motorcycle competitions. Furthermore the relationships between performance-related variables such as crash events, speed of racing and environmental conditions were examined. The ultimate goal of this study was to provide empirically-based foundation knowledge that might be used to assist future rider preparation.

Methods

Methodological approach

In circuit race motorcycling competitions, championships are organized in multiple events, usually performed over several months on different tracks located according to the level of competitions (i.e. club, national or international level). A cross sectional observational research design was used in this study, where performance variables (i.e. time of the fastest racers, values pertaining to braking actions etc.) and event-related data (i.e. track characteristics, weather conditions, etc.) of professional racers (i.e. world championship) were analysed over three consecutive seasons (i.e. 2013-2015). Collating kinematic measurements from official race reports allowed the description of the mechanical stresses experienced by riders during competitions.

Data Sample

Data from competitive seasons 2013, 2014 and 2015 of the top class (i.e. MotoGP™) of the FIM Road Racing Grand Prix World Championship (GPWC) were collected and collated for analysis. The research design involved analysis of publicly available sport performance data, and the institutional ethics review board approved the study. Researchers had no professional, social, financial or cultural relationships that might be considered conflict of interest with respect to the collated data.

Data Source

Performance and event-related data were retrieved from: a) official documents that included circuit information, Race Direction (RD) reports and rider profiles from the official open-access website of the GPWC (i.e. www.motogp.com); and, b) official race reports (i.e. Brake Circuit Identity Cards) from the open-access website of the leading company manufacturing braking systems for racing prototype motorcycles (i.e. Brembo, Italy).

Performance Data

For each competition event (GP), the following quantitative and qualitative variables were selected to quantify the riders' performance: year of event; name of the track where GP was held; length of the track [m]; number of laps needed to complete the GP; race conditions [dry/wet] as declared from RD; air temperature [°C]; humidity [%]; ground temperature [°C]; number of riders crashed during the GP; time needed for the GP-winner rider to complete the race [s]; time needed for the rider finishing in 10^{th} position to complete the race [s]; number of right corners on track; number of left corners on track; longest straight on track [m]; and, number of braking actions per lap. In addition, for each braking action performed in a lap, the following measurements were used to quantify the inertial stress experienced by riders during competitions: speed at the beginning of the braking action [$km{\cdot}h^{-1}$]; speed at the end of the braking action [$km{\cdot}h^{-1}$]; displacement while braking [m]; duration of the braking action [s]; force peak on front brake lever [kgf]. Braking data were mean values recorded during dry races or dry race on-track simulations (i.e. new track on the seasonal calendar), obtained by data logger systems owned by the racing teams equipped with the Brembo braking systems. Body mass [kg], stature [cm], age [years] and brake brand of the top ten riders for each season were also recorded.

In a racing tournament, riders collect points according to their final position at each event. Only the first 15 riders crossing the finish line are awarded championship points in an exponentially decreasing order. In competitions, although the leading rider or group of riders are looked upon as the reference performance for setting the pace of the races, the top ten finishers are usually considered the most competitive athletes in each category or level of competition. Focusing exclusively on the performance of the race winner, especially when a talented rider with a fast bike is synonymous with victory, would restrict the analysis of performances to single machinery-rider binomials, while considering all the finishers, would include the analysis of novice participants or less competitive riders, which would not be representative of the top level of the competition. Therefore, in this study, the mean speed and race duration between the first and the 10th rider have been considered for analysis, which are the top two thirds of the finishers being awarded championship points.

From the aforementioned measurements, the following values were calculated: length of the GP [m]; total number of brakes in a GP; total number of corners in a GP; mean speed (MS) between the 1st and 10th position to complete the GP [$km \cdot h^{-1}$]; GP single lap time (MLT) at MS [s]; mean race duration for the first ten riders [s]; percentage of time spent braking in a MLT [%]; braking ratio in a MLT [s] which is the number of seconds needed to complete one lap at mean speed divided the number of brakes in one lap; curve ratio in a MLT [s] which is the number of seconds needed to complete one lap at mean speed divided by the sum of left and right corners in one lap; and, negative mean acceleration per each braking action [$m \cdot s^{-2}$] (i.e. change of speed divided by the duration of braking).

Inclusion Criteria

At the GPWC, all races are categorised as either wet or dry by RD before the start of the race. The purpose of this classification is to indicate to riders the varying climatic conditions during a race, which affects their choice of tyres and the overall performance. A white flag being waved at the flag marshal posts during the race indicates that the RD (committee responsible for ensuring proper observance of the sport regulations and efficient running of the practice and races) has decided to declare a wet race after it was originally declared dry. In this instance riders are allowed to change bikes during the race to those equipped with wet tyres by entering the pit lane and swapping machinery in front of their assigned pit box.

To standardize the fundamental conditions for performance-related data analysis, the following three criteria needed to be satisfied for the competitions to be included in the analysis: 1) the race was declared dry by RD before the start; 2) in case the white flag was waved at any point during the GP, none of the first ten riders crossing the finish line entered the pit lane during the race; and, 3) the first ten riders crossing the finish line completed the required original number of laps announced for the event in accordance to the official regulations. The braking-related data referred to measurements in dry settings, therefore they were considered pre-standardized. Circuit-related and rider-related data did not require standardization.

Statistical Analysis

Both data gathering and statistical analysis were performed using an open source electronic spread sheet (Open Office 4.1.2). Descriptive statistics (i.e. mean, standard deviation, range) were used to summarise quantitative variables. To estimate the uncertainty of the true mean, 95% confidence limits (CI) for the mean were calculated. Pearson correlation coefficient (r) and its 95% CI using Fisher's z transform was used to explore potential relationships between variables. Trivial, small, moderate and large relationships were considered for r between 0 and 0.1, 0.1 to 0.3, 0.3 to 0.5 and larger than 0.5, respectively.

Results

From a total sample of 54 competitions (18 races per season), 8 races (14.8%) did not satisfy the inclusion criteria (5 wet races, 2 white flags rule applied, 1 race with lap reduction due to exceptional tyre degradation), therefore performance data from a total of 46 competitions (2013 season n=16, 2014 season n=15, 2015 season n=15) in conjunction with the braking data (18 reports per season) were analysed to quantify the riders' load during competition. Twenty-nine out of the thirty (96.7%) riders that ranked in the top ten positions at the end of the three analysed seasons had their motorcycle equipped with the Brembo braking system, therefore braking data reports were considered relevant and valid information to relate to the race reports.

The youngest rider (all males) was 20 years old, while the oldest was 36. The lightest and smallest rider had a body mass of 51 kg and stature of 160 cm, while the heaviest rider was 77 kg and the tallest was 182 cm. (see Table 4.1)

	Season 2013 (n=16)	*Season 2014 (n=15)*	*Season 2015 (n=15)*	*Total Sample (n=46)*
Age (years)	27.1 ± 4	26.2 ± 4	27.5 ± 4	26.9 ± 4
Body mass (kg)	63.2 ± 5.3	63.5 ± 5.2	65 ± 6.7	63.9 ± 5.7
Stature (cm)	171.1 ± 6.2	172.8 ± 6.9	172.8 ± 6.9	172.2 ± 6.5
Mean speed of racing ($km \cdot h^{-1}$)	161.7 ± 6 CI: 158.4 - 164.9	163.6 ± 7 CI: 159.9 - 167.3	164.5 ± 6 CI: 160.9 - 168.1	163.2 ± 6 CI: 161.3 - 165.1
Percentage of braking actions over 300 $km \cdot h^{-1}$	12.9	13.7	13	13.2
Crash per race	2.8 ± 2	3.3 ± 2	3.7 ± 2	3.2 ± 2

Table 4.1. Top ten riders' characteristics and performance variables.
Abbreviations: CI: Confidence interval.

In dry conditions, the riders raced for 43:07 ± 1:39 minutes per race, covering a mean distance of

117.2 ± 3.1 km, riding at a speed of 163.2 ± 6.4 km·h^{-1} (maximum MS in the Australia GP in 2015: 177 km·h^{-1}; minimum MS in the Indianapolis GP in 2013: 151 km·h^{-1}). Increases in MS were observed over the three seasons analysed: 1.2% between 2013 and 2014, and 0.6% between 2014 and 2015. In the 19 different circuits included in the GPWC during these three seasons, riders were required to navigate 15 ± 2 corners and 7 ± 1 braking actions per lap, and the longest straight on track measured 827 ± 223 meters. To complete the required distance during actual competitions, they braked 175 ± 42 times and leaned to corner 372 ± 48 times per race (see Figure 4.1). Maximum values of those technical actions were observed at Assen in the Netherlands, where riders cornered 468 times in the race and at Laguna Seca in the United States, where riders were required to brake 256 times from the beginning to the end of the race. The minimum values were recorded at the Malaysia GP, where riders cornered 300 times and, in the Australia GP, where only 3 brakes per lap were required for a total of 81 braking actions to complete the race.

In dry conditions, a MLT lasted 1:45.5 ± 00:12.7 minutes, where riders spent 28.6 ± 4.9 seconds braking (27% of their racing time). Matching performance-related data with track-specific braking and cornering requirements indicated riders performed a braking action every 11.6 ± 4.1 seconds of racing (i.e. spent accelerating and not using either the throttle or the brakes) that lasted 4.2 ± 0.6 seconds in duration. The riders were in the middle of negotiating a corner every 7.1 ± 0.8 seconds of riding.

Across the 18 GPs per championship, racers faced 124 different braking actions (i.e. entering 124 different corners) during the 2013 and 2014 seasons and 123 actions during the 2015 season. Over 40% of these braking actions were initiated at a speed higher than 260 km·h^{-1} (see count of brakes in Figure 4.2). Although during actual racing the decrease of speed is of a non-linear shape (to minimize the time at a lower speed and to optimally manoeuvre the lean of the motorcycle at the end of the braking phase), riders experienced a mean negative acceleration ranging from 16.5 m·s^{-2} to 2.7 m·s^{-2}, and 25% of the aforementioned inertial stresses were greater than 10 m·s^{-2}. The mean peak force applied on the brake lever during those braking actions increased from 5.1 ± 1.2 kgf in 2013 to 5.4 ± 1.6 kgf in 2014 and 2015, with a maximum value reached at the Argentina GP on 2014 where the mean peak force applied on the brake lever for this track, which requires 8 braking actions per lap, was 8.3 ± 3.3 kgf.

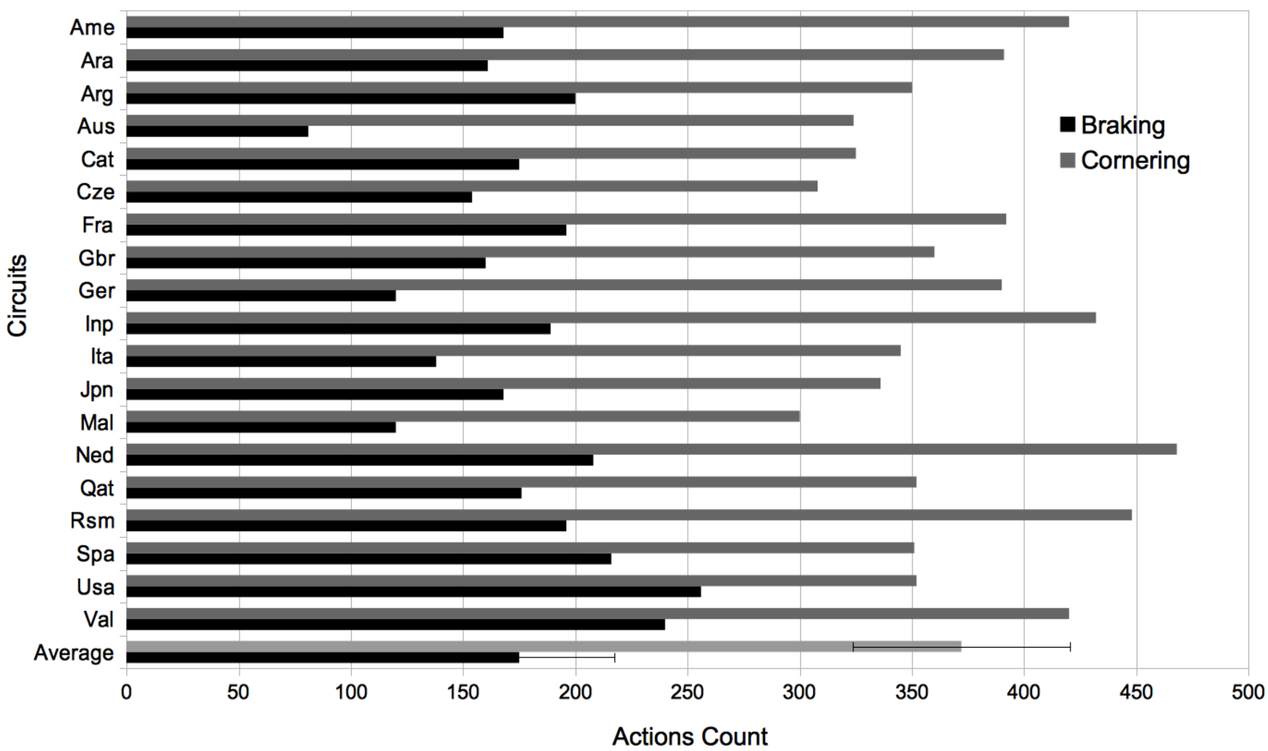

Figure 4.1. Count of braking and cornering actions performed during competitions across different circuits. Abbreviations: (Ame = Circuit of the Americas, USA; Ara = Motorland Aragon, Spain; Arg = Circuit Termas de Rio Hondo, Argentina; Aus = Phillip Island Circuit, Australia; Cat = Circuito de Catalunya, Spain; Cze = Automotodrom Brno, Czech Republic; Fra = Le Mans Circuit, France; Gbr = Silverstone Circuit, UK; Ger = Sachsenring Circuit, Germany; Inp = Indianapolis Motor Speedway, USA; Ita = Mugello Circuit, Italy; Jpn = Twin Ring Motegi, Japan; Mal = Sepang Circuit, Malaysia; Ned = Assen Circuit, the Netherlands; Qat = Losail International Circuit, Qatar;

Rsm = Simoncelli World Circuit Misano, Republic of San Marino; Spa = Circuito de Jerez, Spain; Usa = Laguna Seca Circuit, USA; Val = Ricardo Tormo Circuit, Spain).

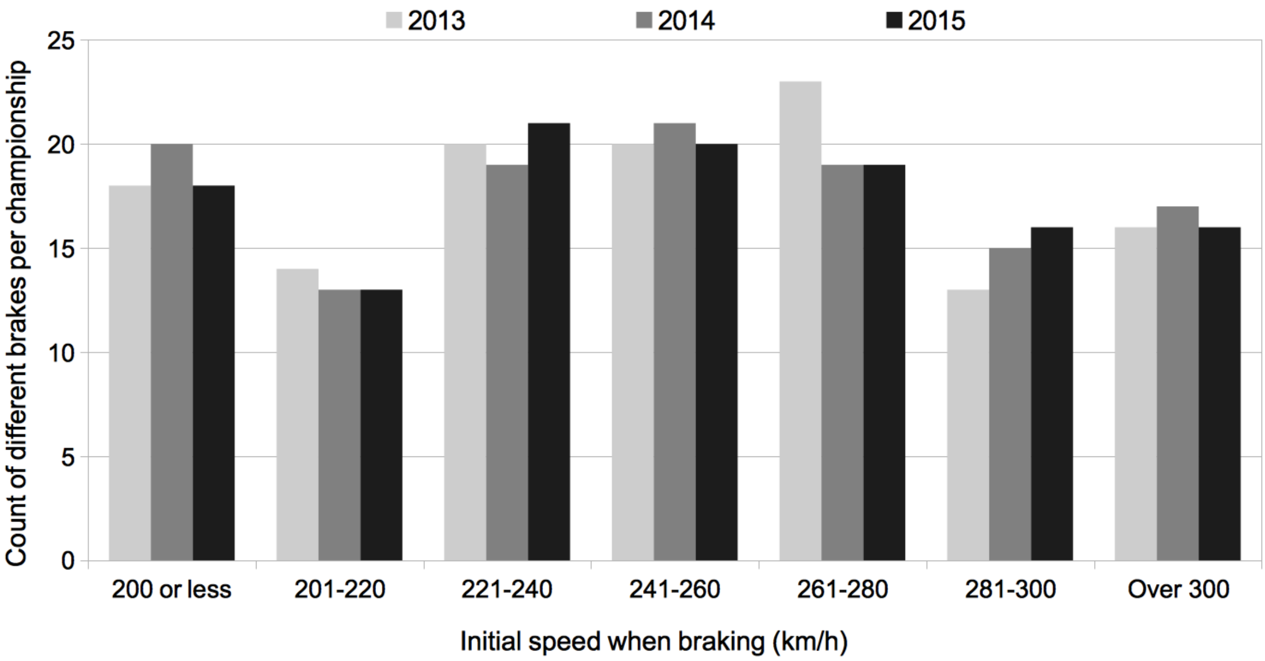

Figure 4.2. Count of braking actions and their initial speed across seasons.

During dry competitions, 3.2 ± 2 riders crashed per race, with a maximum of 7 riders crashing in three events (6.5 % of the total sample analysed). Trivial to small correlations were found ($r < \pm 0.3$) between the count of crashes per race and the speeds of racing (i.e. MS ($r = 0.03$; CI: -0.26 to 0.32) and the mean speed of the winning rider ($r = 0.05$; CI: -0.24 to 0.34)) or the track characteristics (i.e. straight length ($r = 0.08$; CI: -0.21 to 0.36), number of curves on track ($r = -0.13$; CI: -0.41 to 0.16), number of curves per race ($r = -0.28$; CI: -0.52 to 0.01)) or braking variables (i.e. number of brakes per race ($r = -0.16$; CI: -0.43 to 0.14), time spent braking ($r = -0.05$; CI: -0.33 to 0.25), mean braking duration ($r = 0.17$; CI: -0.12 to 0.44), mean peak force on lever ($r = 0.09$; CI: -0.21 to 0.37)). Correlation coefficients were also small (r between 0.1 and 0.3) when relating the count of crashes with the environmental conditions of racing (i.e. air temperature ($r = 0.26$; CI: -0.04

to 0.51), air humidity (r = -0.11; CI: -0.39 to 0.19) and ground temperature (r =0.25; CI: -0.05 to 0.5)). The strongest association (moderate magnitude, r = 0.31; CI: 0.02 to 0.55) was found between crashing events and curve ratio (i.e. MLT divided the sum of left and right corners in that circuit).

Discussion

A few scientific publications have described the metabolic load of circuit race motorcycling (D'Artibale et al., 2007; D'Artibale et al., 2008; D'Artibale et al., 2013; Filaire et al., 2007), however no studies have profiled the forces acting on the rider with direct measurements (i.e. instrumenting the bike or the rider). This paucity of research could be attributed to the difficulty of using experimental apparatus in such unique competitive settings and the tendency for racing teams/factories to operate in strict secrecy so as to maintain a competitive advantage. In addition, being a high-risk and high-cost sport, riders along with teams are reluctant to allow the collection of experimental data, as it is perceived that data collection may influence performance and safety.

Nonetheless this study has profiled the stresses experienced by riders by analysing race results and kinematic data from top-class circuit racing motorcycle competitions. Furthermore, this analysis incorporated information in regards to the crashing events, which are a determinant variable of the final outcome in this sport. With this in mind, the aim of this study was to quantify the physical stresses experienced by riders competing at the top-level in circuit race motorcycling (i.e. FIM Road Racing Grand Prix World Championship) and explore potential relationships between performance related variables such as speed of racing and crashes.

The main findings of this study were: 1) professional top-level riders are relatively light male athletes with a mean stature above 170 cm and a mean age of 27 years; 2) the mean speed of racing has increased over the three years of competitions – riders are going faster; 3) during racing, riders are exposed to a considerable volume of high intensity actions required to both counteract inertial stresses generated by positive and negative accelerations in the horizontal plane while increasing and decreasing speed, as well as counteracting lateral centrifugal forces while cornering; 4) there are no clear relationships between the amount of crashes and competition-related factors (i.e. racing speed, track characteristics, brakes, environmental conditions).

The rider's body mass and stature can be considered influential on riding performance. The final mass of the rider-motorcycle affects the engine power-to-weight ratio and consequently the ability to obtain high accelerations, therefore, since motorcycles are weight-regulated, a lighter and smaller rider intuitively advantages the final performance (D'Artibale et al., 2008; Sánchez Muñoz et al., 2011). Despite anthropometrics not being a focus of this study, the data analysed offer a unique view of the general body size of the top level riders, which may represent valuable information for aspiring riders and future research directions cantered on inertial mechanisms and preparation methods in this sport. Anthropometrically, it can be concluded from the current analysis that professional top-level riders are males who are relatively light (from 63.2 ± 5.3 kg to 65 ± 6.7 kg) in the lower percentile range of stature (from 171.1 ± 6.2 cm to 172.8 ± 6.9 cm) (Fryar et al., 2016). A small and light rider might be particularly advantageous for lower categories of racing (Sánchez Muñoz et al., 2011) where the power-to-weight ratio is more affected by the human portion of the total mass due to a limited engine capacity. However, further data and analysis is required as it may be assumed that professional riders with longer limbs may be biomechanically advantaged in combatting the inertial forces associated with leaning and braking, and as a result successful in riding bigger, heavier and more powerful motorcycles.

The mean speed of racing increased across the three years from 161.7 ± 6 $km{\cdot}h^{-1}$ during the 2013 season to 164.5 ± 6 $km{\cdot}h^{-1}$ during the 2015 championship. Whether this can be attributed to mechanical and/or human factor was beyond the scope of this article, however, the constant improvements of the technological components of the motorcycle such as braking systems, electronic engine power control and tyres compounds no doubt has increased the physical stresses experienced by racers to counteract the forces of faster racing (D'Artibale et al., 2013; Lippi et al., 2007). In particular, since the front brake is used to decelerate the bike in circuit racing motorcycles (operated by a lever with the fingers of the right hand), riders are exposed to frequent and substantial muscular activity in the upper limbs, generating exceptional tension in the forearm region to properly operate the handlebars while counteracting inertial forces acting on the whole body (Barrera-Ochoa et al., 2016; Marina et al., 2011). Findings from this study reported mean peak force applied on the brake lever increasing from 5.1 ± 1.2 kgf in 2013 to 5.4 ± 1.6 kgf in 2014 and 2015. In synergy with these results, the incidence of chronic exertional compartment syndrome of the upper limb seems to be increasing between motorcycle racers in recent years (Barrera-Ochoa et al., 2016; Goubier & Saillant, 2003). Interestingly, even though the use of surgical interventions such as a fasciotomy has proven successful in the treatment of this syndrome, the efficacy of non-operative treatments or preventative methods (i.e. specific muscular strengthening, stretching or technical adaptations) seems unexplored.

Professional riders are required to perform at their best for more than 40 minutes, where they continuously coordinate their technical skills (i.e. synchronised multi-limb actions such as up/downshifting, throttle and brakes control, clutch for some classes) and their postural adaptations in a high-density rhythmical sequence of actions. When averaging the duration of a lap with the track layout, a rider experiences a 4.2 second braking action (i.e. postero-anterior inertial acceleration) every 11.6 seconds of racing and turns the motorcycle into a corner every 7.1 seconds of riding. Leaning a high-speed motorcycle to turn requires application of force on the handlebars (i.e. counter-steering, steering) and to laterally shift rider's body weight (Cossalter, 2006; Evertse, 2010); these actions can be performed up to 400 times per race at the top level of racing (see Figure 4.1). In addition, to minimise their lap-time, riders experience intense accelerations when exiting corners and abrupt decelerations (25% > 1g) when braking. Considering the quantity (175 ± 42 brakes per race), the duration (27% of lap-time), and the intensity of the braking actions (13% begin at speed > 300 $km{\cdot}h^{-1}$ and 40% at above 260 $km{\cdot}h^{-1}$) it can be assumed that racing at professional level requires considerable muscular demands.

Despite finding the high and increasing speed of competitions over three seasons of racing, all but one correlation between the amount of crashes recorded during the races and the factors surrounding these events, were trivial or small. With a mean of 3.2 ± 2 riders crashing each dry race the only predictor of moderate magnitude (r = 0.31; CI: 0.02 to 0.55) was the frequency of turns faced by racers when riding in different track layouts, which might mean connecting corners (i.e. curves where the ideal racing line involves multiple consecutive corners) could represent an extra challenging task when performed at high speed. Other track characteristics such as the number of corners or the length of the main straight (i.e. higher top speeds), braking features, the speed of racing, or the environmental conditions were not significantly correlated with the amount of accidents happening during official top-level races. Perhaps a much larger sample and a more detailed analysis (i.e. site and typology of crash) might clarify information about these unwanted events.

Conclusion

Manoeuvring a motorcycle at high-speed in an official competition setting has been shown to expose the riders to a substantial and complex mechanical load. The main findings and practical applications of this study suggest that: 1) Circuit race motorcycling riders aiming at achieving the top level of the sport might consider monitoring anthropometric measurements and following nutritional plans with the intent of optimizing their body composition i.e. balancing low body weight with the necessary muscular mass to control the forces required to control the motorcycle while racing. 2) The muscular demands of professional riders during top-level competitions are considerable in volume and intensity, especially when considering that official events last three or four consecutive days. Therefore, riders performing at high level should possess pre-requisite levels of cardiovascular and muscular endurance as well as muscular strength. 3) To counteract the repetitive positive and negative inertial stresses of racing, riders should implement training that focuses on site-specific eccentric, isometric and concentric strength in the lower and especially the upper limbs. 4) Due to the exceptional stress accumulated in the upper limbs, in particular in the forearm region (Marina et al., 2011), and due to the potential risks of overload (i.e. surgery to solve forearm compartmental syndrome) (Barrera-Ochoa et al., 2016; Goubier & Saillant, 2003), riders may have particular interest in programming exercises aiming at decreasing the muscular tension and future research may investigate the effects of specific exercises aiming at increasing the elastic properties of the affected tissues (i.e. muscular stretching, high range of motion antagonists exercises, etc.). 5) Due to the quota of racers crashing at each event, in order to minimise injuries, increase confidence and extend a riders career, competitors might consider including crash-skills training in their preparation plan (i.e. tumbling techniques).

Finally, this study provides original and novel information quantifying indirectly the mechanical stresses and subsequent muscular demands of top-level circuit race motorcycling. Furthermore, no other scientific publications studied crashes and performance-related variables. It is acknowledged that there a number of limitations of the current analysis, however, until riders can be directly instrumented and in-field measurements collected across a number of racers and teams, then the methodological approach undertaken in this study would seem very useful to provide fundamental information for the design of rider preparation programs.

Chapter 5 – Inertial stresses of national and international motorcycle circuit racing riders.

This chapter comprises a manuscript currently under review for re-submission to a scientific Journal.

Author contribution: D'Artibale E: 85%; Neville J: 7.5%; Cronin JB: 7.5%

Prelude

Analysing top-level performance-related data, as in Chapters 3 and 4, allowed the authors to indirectly describe the load of professional racing. In particular, findings from the previous chapter provided an insight of the mechanical profile of racers, and suggested that top-level riders are exposed to a considerable volume of high intensity actions (i.e. >40% of brakes initiated at speeds higher than 260 km/h and 13.2% over 300 km/h). These results highlighted the key role that inertial stresses such as braking and accelerating play in regards to the muscular load of racing, however, no previous research has been published quantifying them. Expanding the knowledge about the magnitude of such stresses by directly measuring kinematic data would support the mission of profiling racers and identifying factors important to their performance. Therefore, to quantify the stress that major actions such as braking and accelerating to exit corners cause on riders, this chapter is a unique study collecting and elaborating upon direct measurements of kinematic values from real competitions.

Introduction

Motorcycle racing exposes riders to considerable mechanical loading during circuit competitions (D'Artibale et al., 2018a; D'Artibale, Laursen, & Cronin, 2018b). Indeed, to minimise lap-time, riders aim to increase their mean speed throughout the lap, therefore late braking, high mid-cornering speed and early and intense corner exits are strategies employed by skilled competitive riders (Corno et al., 2008; D'Artibale et al., 2018b; Ibbot, 2013). These manoeuvres expose the rider to abrupt postero-anterior decelerations and antero-posterior accelerations, as well as centrifugal forces balanced by leaning the motorcycle into corners (Cocco, 2005; D'Artibale et al., 2018a; D'Artibale et al., 2018b; D'Artibale et al., 2008; Ibbot, 2013). Profiling these inertial stresses would help understand the physical load and muscular demands in this population of athletes.

Recently, researchers have quantified the physical actions of top-level riders, measuring the volume and frequency of brakes and corners per race, as well as calculating the intensity of the braking actions by using the kinematic variables from race reports. At professional level, in a single race, riders brake on average more than 170 times, and over 40% of those postero-anterior negative accelerations experienced by the system bike-rider are initiated at a speed higher than 260 km/h (D'Artibale et al., 2018b). Using top-level carbon disk brakes, circuit racers experience a mean negative acceleration ranging from 2.7 to 16.5 m/s^2; and despite 25% of those braking actions generating a mean inertial stress greater than 1 g, there is no published research describing the forces that riders are required to counteract whilst racing (D'Artibale et al., 2018b).

According to the level-proportioned number of laps per race, the load induced by the repetitive cycle of technical actions (i.e. accelerating, braking, cornering) might be considered of lower magnitude at lower categories. However, even though this sport is highly supported by forefront technology, direct measurements of these mechanical stresses experienced by racers remain unpublished. Indeed, currently there are no available studies that have instrumented the motorcycle or the rider with the intent of directly measuring the physical stresses of competitions with the objective of estimating the relative muscular strength requirements of racing. With this in mind, and based on previous findings (D'Artibale et al., 2018b), it is hypothesised that the inertial stress from the braking and corner exiting actions is substantial during racing, and perhaps different across categories. Therefore, the aims of this study were to: 1) directly measure and quantify the negative and positive accelerations that riders experience during changes of speed (i.e. braking actions and corner exits), to estimate the forces experienced on their centre of gravity while riding in dry conditions during competitions; 2) investigate potential differences between categories of racing (i.e. entry-level and mid class); and, 3) determine potential relationships between estimated inertial loads and ranking level or experience of riders.

Methods

Design and methodological approach

A cross-sectional descriptive design was implemented, where circuit racing motorcycles were equipped with a 10 Hz GPS unit to measure and record changes of velocity and positions on track while racing. Measurements were collected from racers competing in different categories and on different tracks during dry sessions (i.e. free practice, qualifying or race) of official competitive events.

Participants

During the 2016 racing season, riders competing in the Italian circuit racing national championship (namely Campionato Italiano Velocitá), European Junior Cup and the World SuperSport championship were randomly invited to take part into this study. Participants were provided with an information sheet, signed a consent form and were allowed to withdraw from the study at any time. Twenty-three riders (22 males and one female) volunteered to take part into this study. The research protocol was approved by the institutional ethics review board (AUTEC reference number 16/109).

Biomechanical Model

Due to the novelty of the analysis, a simplified biomechanical model was used for this study. Calculation of estimated forces was based on the horizontal component of the acceleration, excluding the drag. Vertical accelerations were considered negligible (i.e. no jumps involved) and also lateral forces involved in cornering were omitted from the model (Figure 5.1).

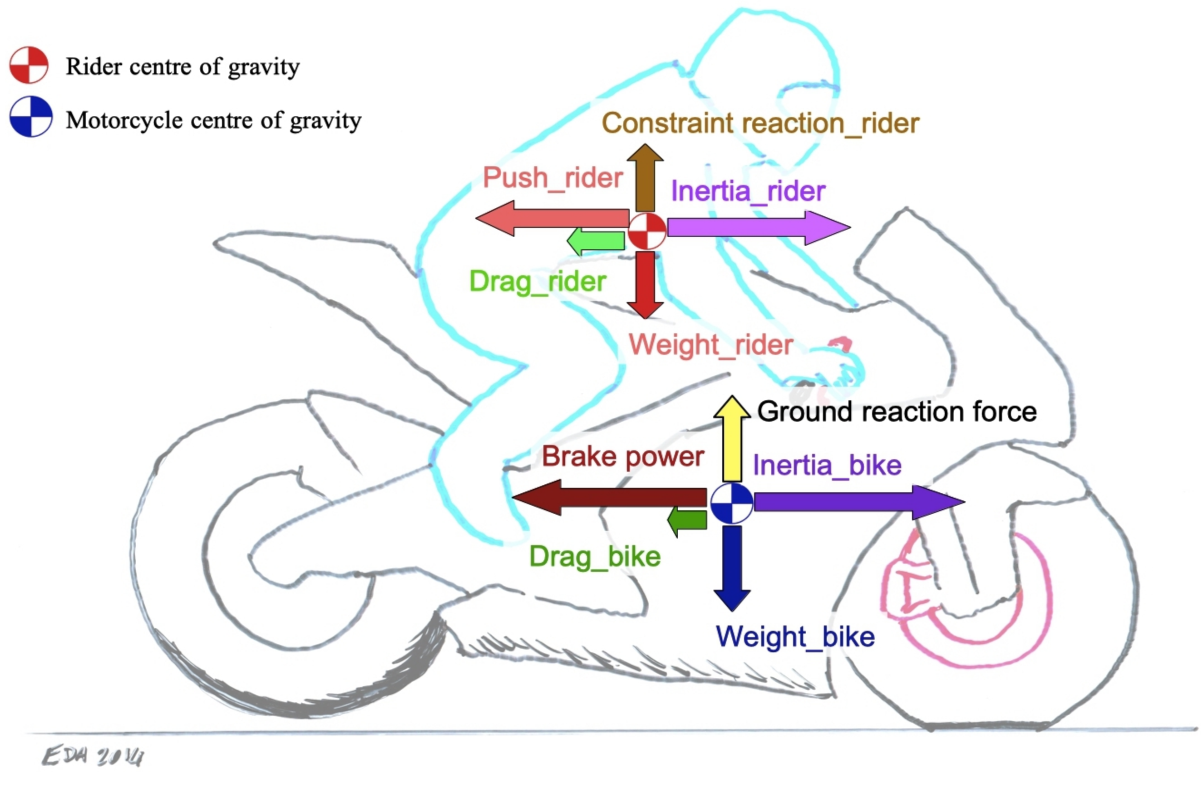

Figure 5.1. Biomechanical model simplified, describing static calculation of dynamic forces acting on the centres of gravity of a motorcycle and a fully equipped rider during a braking action in racing.

Indeed, motorcycle circuit racers combat centrifugal forces by leaning the motorcycle (i.e. rolling) and moving their bodies (i.e. hanging-off) towards the inside of the corner. Moreover, the practicality of this elementary model was supported by the filtering applied in data handling, which aimed at isolating the braking and corner exit actions. Despite the pitching, yawing and the horizontal inertial forces have been considered being absorbed by the rider through the points of contact with the motorcycle (i.e. hands, buttocks, inner thighs and knees, and feet), the estimation of load was calculated by considering the human element as a single system.

Measurements

The European Junior Cup (EJC) was an entry-level category run with single-manufacturer, stock version motorcycles equipped with a 650 cc four-cylinders engine (approximately 180 kg and 80 bhp at rear wheel); while the Italian National SuperSport (NSS) and the World SuperSport (WSS) were a mid-class category run with competition-prepared 600 cc four-cylinders or 675 cc three-cylinders engine (minimum weight 161 kg and approximately 138 bhp and 145 bhp for NSS and WSS respectively). Those championships were regulated from the same tyre supplier and data were collected in equivalent environmental conditions at 13 different circuits.

Body mass of the participant riders wearing the full protective equipment was measured with a 100 gr-accuracy body weight electronic scale (Paula, Korona, Germany) immediately after the riding sessions. At any time during the 3-day events, racers were also required to complete a one-page athlete-background form to assess years and level of riding experience as well as potential titles.

GPS units Qstarz BT-Q1000eX sampling at 10 Hz and QRacing software (Qstarz International Co. Ltd, Taipei, Taiwan) were positioned on the tank or the tail of the motorcycle facing upward to record speed during riding. Widespread use of the same device in racing environment, and previous pilot testing established the utility and reliability of this experimental setup.

Data Handling

At the end of each session where GPS measurements were collected, the rider selected one ideal race-pace lap from the list of his/her recorded dry laps. This selection identified a "realistic-to-maintain competitive pace lap" between the fastest laps measured at that track and could be selected between his/her laps of any available dry session (i.e. free practice, qualifying or race). Therefore, a single lap per circuit was analysed for each participant. A ranking value (Top third, Mid third, Low third) was given at each selected pace-lap according to the result of that rider at the chequered flag of that respective competition.

Also, for each participant, an experience index ranging from 0 to 100 was calculated by adding scores in the five areas collected with the athlete-background form. The five areas were: years of competitions (score from 0 to 20 on a scale from 0 to 20 years of racing); participation to other competitive motorsports (score from 0 to 5 on a scale from none to regular competitor in a motorcycle discipline in addition to road racing); number of races accumulated (score from 0 to 25 on a scale from 0 to more than 200 races); level of competition (score from 0 to 20 on a bi-dimensional scale with frequency and from regional to world championship level); titles awarded (score from 0 to 30 on a scale from 0 regional title to 5 or more world titles).

Following the in-track measurements, speed data from pace-laps were exported into an open source electronic spread sheet (Open Office 4.1.2, Apache Software Foundation, MD, U.S.A.) and organized prior to being imported into MATLAB (version R2016b, MathWorks, MA, U.S.A.) to identify selected performance variables.

A MATLAB script was used to identify the decelerations (i.e. active braking and loss of speed due to engine braking actions) and accelerations (i.e. corner exits) inside each individual pace-lap, by finding local maximum and local minimum speed corresponding with the start and end times of speed changes (Figure 5.2).

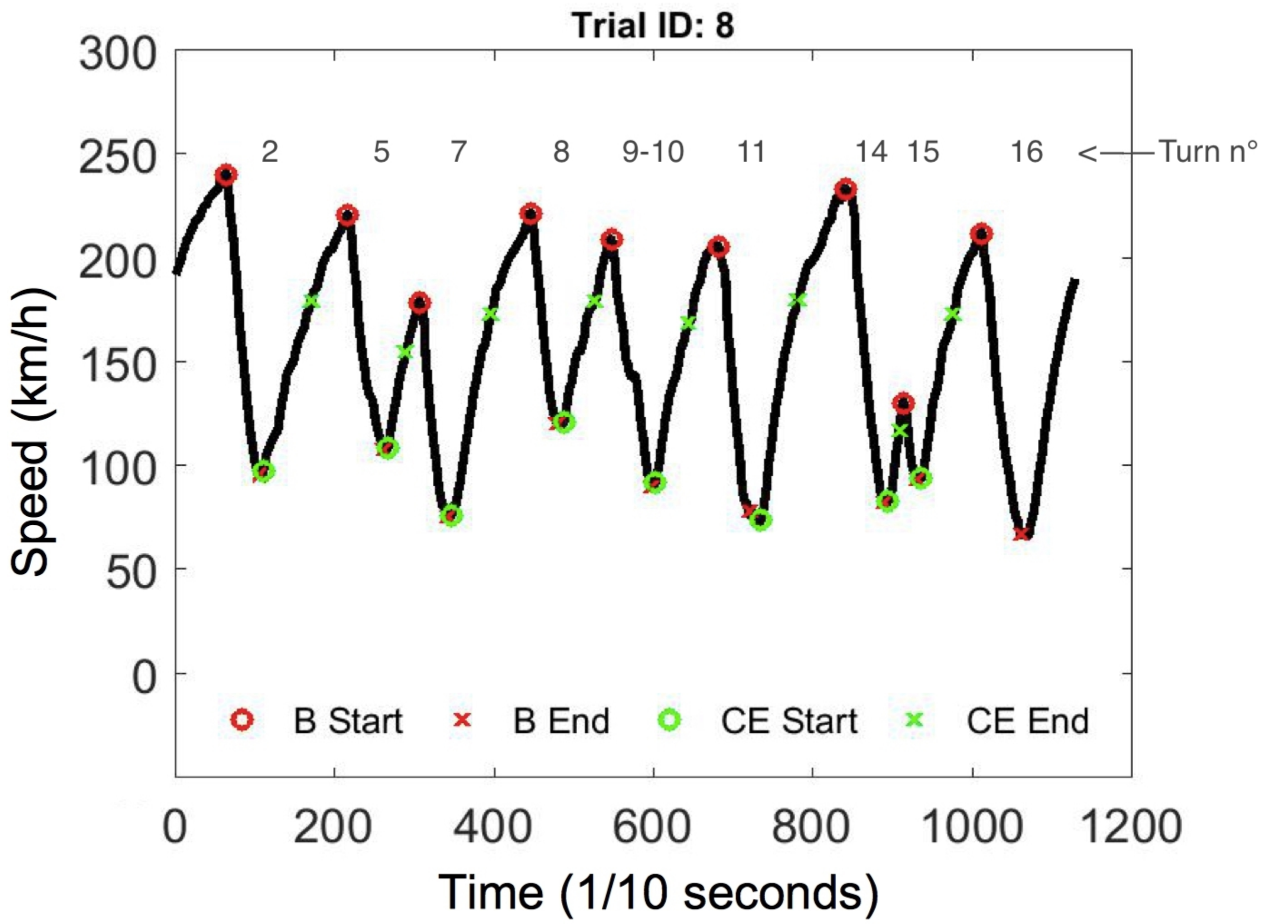

Figure 5.2. Example of a selected ideal race-pace single lap in the NSS class at Imola track with variables brake (B) and corner exit (CE) identified.

To accurately isolate the decelerations in each pace-lap, the following criteria were used:

1) To minimize the effects of GPS error and to exclude passive deceleration before or after the active braking took place (i.e. wind resistance when riders move from the aerodynamic position a few moments before the brakes are engaged or mid-corner throttle-off), two algorithms were implemented: a) For passive deceleration prior to braking: the detection of the start of the deceleration period was moved forward to 99.5% of the top speed (within a maximum range of 2 seconds forward); b) For passive deceleration after braking: the detection of the end of the

deceleration period was moved backward to 101.5% of the minimum speed (within a maximum range of 2 seconds backward);

2) To avoid the detection of short loss of acceleration (i.e. gear-shifting or short shut off in a kink of the track layout) a filter of a minimum change in velocity of 5 km/h and 0.5 seconds was applied;

3) To exclude extended throttle-off portions (i.e. riding through a "change of direction" section or connecting corners in the track), decelerations smaller than 10 km/h were not included in the analysis.

Also, for each brake, three more measurements were collected: the initial speed [km/h] at the start of the braking action, the duration [s] of the individual brake, and a value indicating where the mean deceleration occurred in a percentage scale of the peak deceleration, suggesting the uniformity of braking.

To accurately isolate the accelerations exiting the corners in each individual pace-lap, the following criteria were used:

1) To minimize the effects of GPS error and to exclude the transition phase, two algorithms were implemented: a) the detection of the start of the acceleration period was moved forward to 101.5% of the local minimum speed (mirroring the end of the deceleration); and, b) the detection of the end of the acceleration period was moved backward to 99.5% of the maximum speed; and,

2) To confine the meaningful part of the corner exit (when the motorcycle engine generates the bigger portion of power), the end of the acceleration was detected when 66.7% of the difference between the end and start speeds of the acceleration period determined in previous criteria was achieved.

For each identified brake and corner exit, peak and mean acceleration [m/s^2] were found. Then, the inertial forces [N] acting on the riders' centre of gravity were calculated in each individual case with the formula $F = m \cdot a$.

Statistical Analysis

Descriptive statistics were used to summarise measurements and describe the inertial stress (i.e. calculated forces) riders were exposed to during racing. Differences in the means were explored via magnitude-based analysis (Hopkins, Batterham, Marshall, & Hanin, 2009), calculating percent differences, standardized difference between means, and the uncertainty of the true mean (i.e. 95% confidence limits (CI)). Thresholds of 0.2, 0.6, 1.2, 2.0 and 4.0 were used to identify trivial, small, moderate, large and very large standardized difference between means, respectively (Hopkins et al., 2009). Pearson correlation (r) was used to test potential relationships between variables, and statistical significance was set at $p = 0.05$. Softwares Open Office 4.1.2 and IBM SPSS version 25 (International Business Machines Corp, NY, USA) were used to perform the statistical analysis.

Results

Forty-eight ideal race-pace laps containing 425 braking actions and 397 corner exit accelerations were collected from 23 riders participating during the season (Table 5.1).

	Riders	Laps	Brake	Corner Exit	Circuits	Low Rank	Mid Rank	Top Rank	Body Mass fully equipped (kg)	Experience Index
EJC	9	16	126	115	5	-	7	9	77.8 ± 7.6	39 ± 9.8
NSS	7	10	95	95	4	3	1	6	78.7 ± 6.4	48.5 ± 21.4
WSS	7	22	204	187	10	15	1	6	76.5 ± 4.5	53.7 ± 10

Table 5.1. Sample size, ranking and participants characteristics for the three different classes: EJC: European Junior Cup; NSS: National SuperSport; WSS: World SuperSport.

Individual inertial forces generated during the brakes and the corner exits were grouped according to the three classes of competition and measures of central tendency are reported in Table 5.2. Both the mean deceleration in braking and the mean acceleration in corner exits increased with the higher level of competition and motorcycle power (range from 6% to 28%). Interestingly, the highest peaks were associated with the NSS category, perhaps due to the prevalence of data from the Mugello circuit (Table 5.3).

Class	Stats	Mean Braking [N]	Peak Braking [N]	Braking uniformity [%]	Mean Corner Exit [N]	Peak Corner Exit [N]
EJC	mean ± SD	476 ± 118	923 ± 294	53.7 ± 11.0	300 ± 80.6	551 ± 288
	median	478	928	52.9	291	483
	95% CI	(455 – 497)	(871 – 975)	(51.8 – 55.6)	(285 – 315)	(498 – 604)
NSS	mean ± SD	505 ± 124	1026 ± 458	53.8 ± 13.5	362 ± 120	629 ± 227
	median	521	933	52.0	347	574
	95% CI	(479 – 530)	(932 – 1119)	(51 – 56.5)	(337 – 386)	(582 – 675)
WSS	mean ± SD	513 ± 133	929 ± 350	58.5 ± 12.2	384 ± 108	607 ± 218
	median	523	882	58.7	392	571
	95% CI	(494 – 531)	(880 – 977)	(56.8 – 60.1)	(368 – 400)	(576 – 639)

Table 5.2. Central tendencies of inertial forces and braking uniformity in different classes.

	Aragon	Assen	Buriram	Doha	Donington	Imola	Jerez	Lausitzring	Magione	Magny Cours	Misano	Mugello	Vallelunga
EJC	-	1	-	-	8	-	1	-	-	1	5	-	-
NSS	-	-	-	-	-	2	-	-	1	-	-	4	3
WSS	1	2	1	1	4	2	3	2	-	3	3	-	-

Table 5.3. Selected single ideal race-pace laps collected on different tracks.

Braking actions and forces

Realising the data describes different speeds of racing from different circuits, and the criteria determining inclusion into the analysis, the following observations were made. Riders in EJC performed 7.9 ± 1 brakes per lap, while riders in NSS and WSS recorded 9.5 ± 1.7 and 9.3 ± 1.7 brakes per lap, respectively. Therefore, EJC riders faced 87 ± 11 brakes per race, while riders in

NSS braked 144 ± 14 times (+66%) and WSS riders performed 171 ± 28 brakes (+97% compared to EJC) at each race in the sample. In EJC measurements, 29.3% of the lap time was spent braking, and this ratio increased to 32.1% in NSS and 33.8% in WSS. On average, a braking action lasting 3.9 s was initiated every 9.5 s in EJC competitions. More frequent changes of speed were observed in higher classes, riders in NSS braking for 3.6 s every 7.7 s and riders in WSS braking for 3.8 s every 7.5 s.

Obviously, the differences in these profiles are influenced by the acceleration and deceleration capacities of the motorcycles; in fact, in 77% of cases, EJC riders initiated braking below 200 km/h, and they never exceeded the 220 km/h (top speed measured in EJC: 214 km/h). Alternatively, NSS and WSS racers braked above 200 km/h for 42% and 49% of times respectively, and experienced braking above 240 km/h in 8% and 12% of cases, respectively (top speed of both mid-classes: 273 km/h, see Figure 5.3).

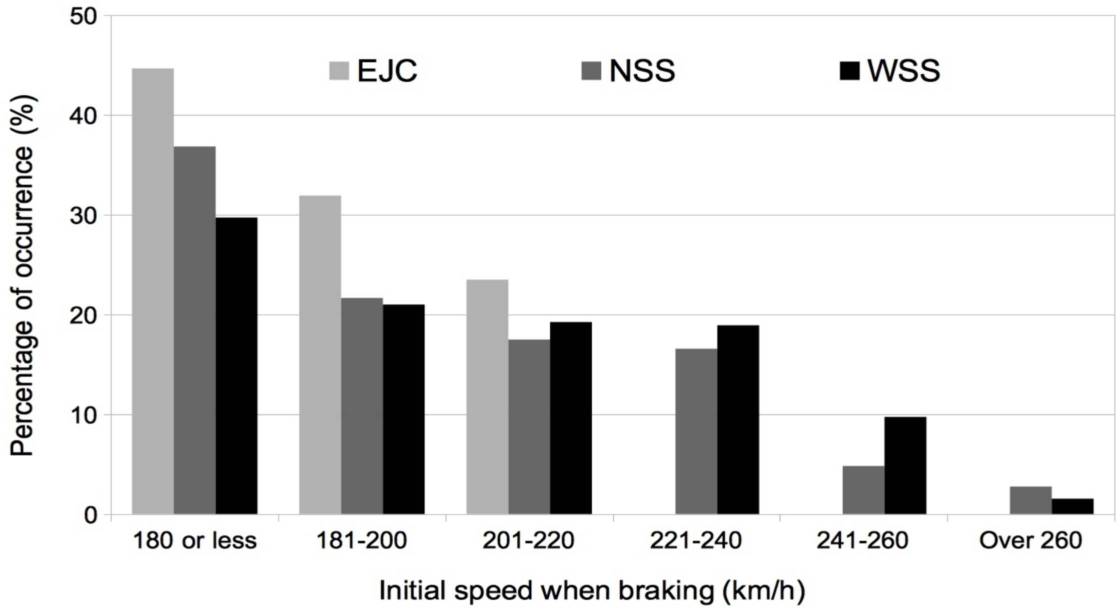

Figure 5.3. Percentage of occurrence of braking actions and their initial speed across classes. Abbreviations: EJC = European Junior Cup; NSS = National SuperSport 600; WSS = World SuperSport 600.

In the EJC class, the calculated inertial mean force acting on the rider centre of gravity for each braking action was 476 ± 118 N, the forces on average 6% and 8% greater in NSS and WSS respectively (see Table 5.2). However, the standardized difference between means of different classes was small: 0.23 between EJC and NSS, and 0.29 between EJC and WSS.

The brake uniformity was similar between EJC and NSS (i.e. 95% CI: 51.8 – 55.6 and 51 – 56.5, respectively) while the mean braking uniformity of WSS was approximately 9% greater (i.e. 95% CI: 56.8 – 60.1). The standardized difference between means of brake uniformity was also small: 0.36 between NSS and WSS, and 0.41 between EJC and WSS.

Forces of accelerations and associations

The mean inertial forces generated while exiting the corners were found to be 20% and 28% higher in NSS and WSS respectively, compared to 300 ± 80.6 N measured in EJC class. The standardized difference between means was moderate: 0.61 between EJC and NSS, and 0.89 between EJC and WSS. The strongest relationship between variables was found between the mean force in corner exits and the mass-to-power ratio ($r = -0.70$; $p < 0.01$). In addition, also the percentage of time spent braking was found having a large negative correlation with the mass-to-power ratio ($r = -0.60$; $p < 0.01$), and a moderate correlation with the final ranking value ($r = 0.50$; $p < 0.01$).

Interestingly, a moderate positive relationship was observed between the experience index and the braking uniformity ($r = 0.46$; $p < 0.01$).

Subgrouping classes

The racing events at different circuits (see Table 5.3), the limited sample size, and the range of rider's body mass (i.e. 68.5 – 89 kg), necessitated careful consideration of the statistical procedures to be utilised to describe main effects. For the step between the entry class (EJC) and the mid-class

(WSS), five couples of observations (n = 10 race-pace laps), that were collected at the same circuits under the same conditions, were isolated for further statistical analysis. When isolating same-circuit data, on average, the lap-time of the EJC sample was 108 % ± 1 % the lap-time of WSS riders and inertial forces were greater in the faster class from a minimum of 5 % to a max of 33 % (Table 5.4). The largest standardized difference between means was in the mean force at corner exits and resulted moderate (0.93).

EJC – WSS	Mean Braking	Peak Braking	Braking uniformity	Mean Corner Exit	Peak Corner Exit
Δ	16%	5%	15%	33%	25%
Standardized difference between means	0.59	0.13	0.63	0.93	0.65

Table 5.4. Magnitude of difference between classes EJC and WSS in five circuits (Assen, Donington, Jerez, Magny-Cours, Misano).

Signal check

The validity of the sampling frequency for capturing events of importance in the speed signal, was quantified using a Fourier analysis on the isolated deceleration periods in the 48 observations (i.e. ideal race-pace laps) used for this study (see Figure 5.4). The results indicated that the signal is dominated by low frequencies and the amplitude of the harmonic components becomes negligible above 2-3 Hz. Given the duration of such events (mean brake duration 3.76 ± 1.34 seconds; mean full acceleration duration 5.75 ± 3.6 seconds) sampling at 10 Hz (becoming 5 Hz according to the Nyquist-Shannon theorem) was considered ample to reconstruct the signal with confidence to satisfy the purposes of this study.

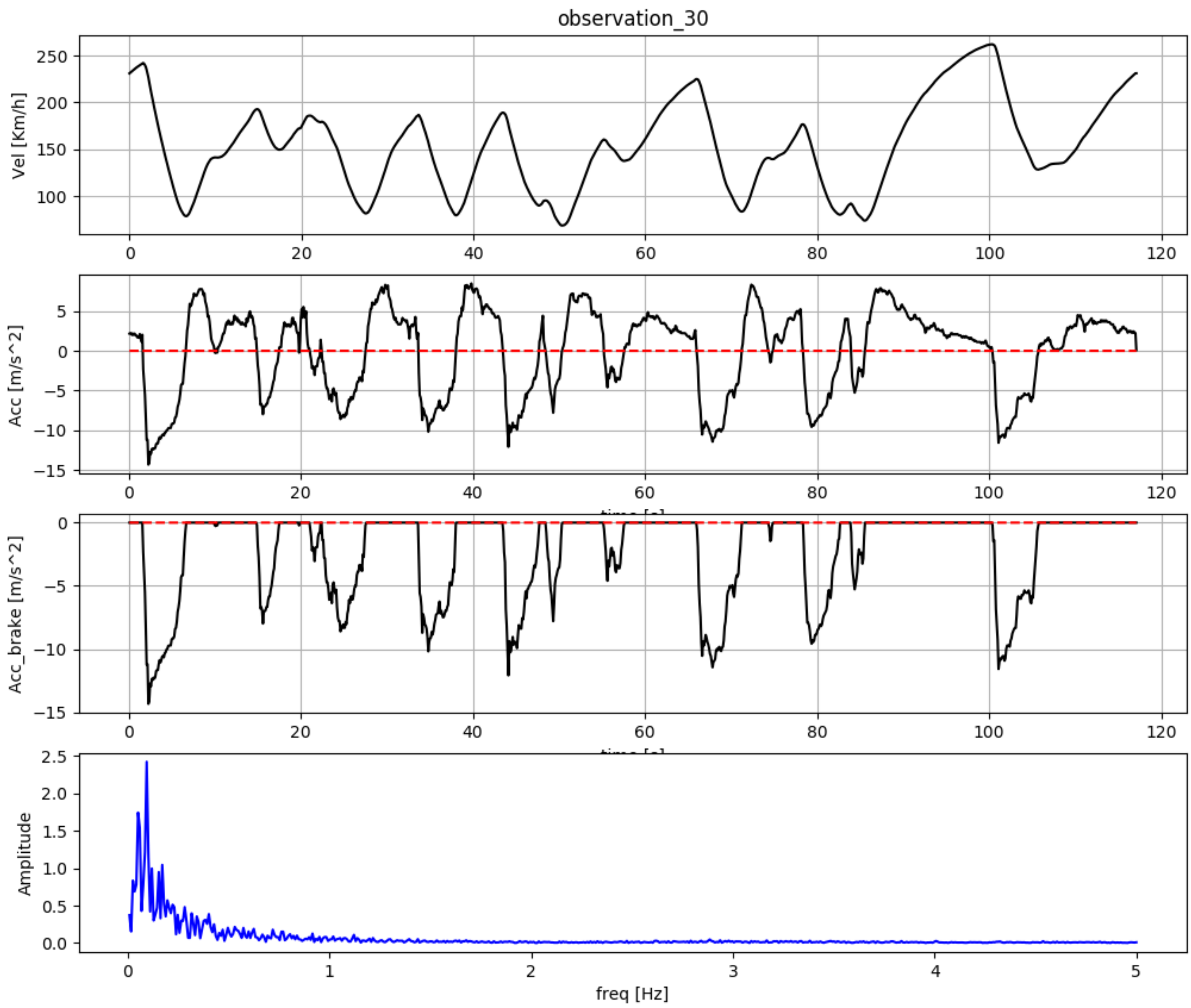

Figure 5.4. Fourier analysis of the signal on the isolated deceleration periods in one observation.

Discussion

While racing, the positive and negative accelerations of the reference frame (i.e. the motorcycle) produce pseudo forces acting on the riders. Despite the advanced technology involved in motorcycle circuit racing, direct measurements of mechanical stresses experienced by riders remain unpublished (D'Artibale et al., 2018a). To our knowledge, this study is the first to have instrumented multiple motorcycles with the intent of directly measuring the inertial forces competitors are required to accommodate, with the objective of estimating the relative muscular requirements of racing.

The main findings of this study were: 1) in national and world level SuperSport600 motorcycle circuit racing official competitions, riders experience braking activity which is considerable in volume, frequency and intensity. In a single dry race, braking actions range from 144 to 171 times, they happen every 7-8 seconds, and each one generates an inertial load on average above 500 N, with peaks about double this load. 2) The inertial force experienced when exiting the corners is related to the motorcycle mass-to-power ratio, and in mid-class category is above 70% of the braking force. 3) Despite statistical moderate-to-small differences in inertial forces between the entry-level class (European Junior Cup 2016) and the SuperSport600 class, when riders move up into this faster category, they will be required to control forces 33% more intense when exiting the corners, and 16% greater braking actions, which both occur over a bigger volume of repetitions due to the longer races.

Decelerations

The braking action is a crucial part in the performance of a racer, its intensity and its modulation influencing the lap-time and determining the inertial load acting upon the rider. In this study, the parameters of mean frequency, volume, duration and intensity of the braking actions have been quantified in entry and mid-class categories, suggesting that competitive riding requires specific muscular demands. Considering that riders spent approximately a third of their lap-time (from 29% to 34%) pulling the brake lever to slow their motion, and acknowledging that they experience a rhythmical sequence of inertial forces during the whole race (see Figure 5.2), reaching peaks of approximately 1000 N during the hardest brakes, it is no surprise that the chronic exertional compartment syndrome of the forearm is the most common muscular overload in this sport (Barrera-Ochoa et al., 2016; D'Artibale et al., 2018a; Gondolini et al., 2019).

During the abrupt braking action, the mass of the rider is pushed forward with a force on average above 500 N in the 600 cc class (i.e. pitching phase). While the rider's centre of gravity is subject to this mechanical stress, lasting approximately 4 seconds, the racer is required to have full control of the handlebars and body position, in order to modulate the motorcycle yawing and rolling, so as to optimise the racing line and speed for the mid-cornering phase (Cossalter, 2006; Evertse, 2010; Ibbot, 2013). Future research might be able to describe the postural strategies adopted by riders to absorb the postero-anterior inertial forces, to quantify the different muscular activations and loads, however, due to the complex mechanical behaviour of the human body during riding, and the accuracy required in inverse dynamics, measuring these movements will be challenging (Gruber, Ruder, Denoth, & Schneider, 1998).

In conclusion, the large negative correlation between the percentage of time spent braking and the mass-to-power ratio, confirms that riders aboard faster motorcycles are subject to larger mechanical stresses; nevertheless, when comparing the EJC with the WSS class, despite the 16% gap in inertial force due to braking and the 15% increase in braking uniformity, only moderate standardized differences between means were reported (0.59 and 0.63, respectively). Considering that top-level motorcycle circuit racing (i.e. MotoGP, Superbike) is performed at higher speeds with more powerful braking systems (D'Artibale et al., 2018b), the demands of the deceleration periods appear to be substantial; however, the muscular strategies to deal with such stresses are still to be clarified.

Accelerations

The data from this study also provide a quantitative description of the mechanical load that competitive national and international racers are required to counteract when exiting corners. In the SuperSport600 class (mass-to-power ratio just above 1.1), every time the riders twist the throttle to rush/accelerate to the next corner, they experience average inertial resistances from 337 to 400 N, with peaks passing 600 N (Table 5.2). Such effort, sustained by the upper limbs anchored to the handlebars, and by the lower limbs, grasping the tank and loading the foot-pegs to optimise the posterior tyre grip, is 75% of the inertial forces associated with braking in WSS. These postural responses to the accelerations can be considered a substantial contribution to muscular work and are no doubt magnified when racing motorcycles with mass-to-power ratio <1 (i.e. classes with 1000cc engines), where 300 km/h are often surpassed (D'Artibale et al., 2018a; D'Artibale et al., 2018b).

Moreover, the quantity and duration of such accelerations, the repetitive alternations with braking actions and the postural/muscular demands of cornering, combined with the hormonal responses due to high speed racing – almost half of accelerations terminate over 200 km/h (Figure 5.3) – may explain the cardiovascular and metabolic demands of motorcycle circuit racing i.e. mechanical demands influences metabolic demands (Ascensão et al., 2007; D'Artibale et al., 2018a; D'Artibale et al., 2008; D'Artibale et al., 2013; D'Artibale et al., 2007; Filaire et al., 2007; Tsopanakis & Tsopanakis, 1998).

Progression between categories

The number of laps in a race increases with the higher category and level of competition, therefore both higher volumes of riding actions and mechanical/inertial stresses of higher intensity are expected with bigger motorcycles. Indeed, a potential rider moving from the entry level category to the mid-class of competition (i.e. from EJC to WSS) would be required to manage a 97% increase in quantity of braking actions due to longer races, and each inertial postero-anterior force due to braking would be, on average, more homogenous (+15%) and more intense (+16%) (Table 5.4).

Moreover, racing with a low mass-to-power ratio motorcycle translates in dealing with a powered two-wheeler system build to reach top speed in a short time, therefore considerable inertial forces due to high accelerations are expected to be involved. In fact, when isolating same-circuit data in

EJC and WSS categories, riders have been reported to experience 33% larger inertial forces at corner exits, to perform lap-times 8% shorter. Obviously, profiling these mechanical stresses contributes in better understanding performances across classes of motorcycle racing, and could guide specificity of training to better effect, to assist rider's progression up categories of competition.

Limitations

These in-field measurements under real competitive conditions provide valuable and specific data, however, the authors recognise the following limitations in this study: 1) the calculation of forces experienced on riders' centre of gravity when braking or accelerating did not take into account the drag forces due to the anatomical areas exposed to frontal air resistance; 2) the calculation of inertial forces acting on the riders did not explain how the riders act to resist them or which muscular regions were activated; 3) even though criteria to isolate the active braking were applied, the identified brakes might include lower magnitude maneuvers where mainly engine braking was used to connect consecutive corners; 4) in each selected race-pace lap, the last acceleration (exiting the last corner before the start-finish line) was not identified from the MATLAB coding due to the lack of detected local maximum (lap-data ends on finish line, see Figure 5.2); 5) the sample is limited and there is no data from the faster and more powerful categories (i.e. various 1000 cc classes); and, 6) the low acquisition rate may increase the error between the measured velocity changes and the real ones.

Conclusion

The performance in motorcycle circuit racing exposes riders to mechanical demands due to the positive and negative inertial stresses generated by the alternation of accelerations and decelerations whilst competing. Direct measurements of longitudinal accelerations during dry official races in entry and mid-class categories suggest that competitive riding requires specific muscular demands due to the mean frequency, volume, duration and intensity of the braking and corner-exits actions. Riders competing in national and world level SuperSport600 championships experience from 144 to 171 brakes per race, happening every 7-8 seconds of racing. The intensity of the inertial force during braking was estimated on average above 500 N, with peaks about double this load, while exiting the corners generated inertial forces on average greater than 360 N in the mid-class category (i.e. SuperSport600). Despite small to moderate standardized difference between means of entry-level and mid-class inertial forces intensities, and no strong relationships found between inertial loads, ranking levels and riders' experience indexes, this study quantified the mechanical stresses of competitive riders and profiled loads across different categories.

The findings of this study provide novel information useful for the design of training programmes aiming at preparing riders for competition (Appendix B). Despite the interpretation and application of these results will vary according to the several classes and levels of competitions, they offer a valuable starting point in quantifying the muscular demands of motorcycle racing, and combined with the findings of D'Artibale et al. (2018b), they enhance the knowledge and understanding of the performance model for circuit racers. To explore preventative strategies to muscular overload (i.e. chronic exertional compartment syndrome of the forearm) and deepen specificity of physical preparation programmes for motorcycle circuit racers, future research is required to describe the postural strategies adopted by riders to absorb those inertial forces, and solve the challenges associated with quantifying the different muscular activations and respective loads during real competitions.

Chapter 6 – Core temperature and pre-cooling strategies in motorcycle circuit racing riders during official competitions.

This chapter comprises a manuscript that will be submitted for publication.

Author contribution: D'Artibale E: 87%; Laursen P: 8%; Cronin JB: 5%

Prelude

Following the creation of a general profile of the main characteristics of the sport (Chapters 2 and 3), the thesis had been focusing on profiling the mechanical loads of motorcycle racing (Chapters 4 and 5). Findings suggest that riders are exposed to a complex interaction of stresses, therefore a multidisciplinary approach supports answering the overarching question: "Which physical and cognitive factors are important in optimising the riders' performance in motorcycle circuit racing competitions?". Considering the mechanical demands due to the positive and negative inertial stresses the rider experiences, coupled with the thermal stress associated with wearing protective equipment in hot environments, profiling the motorcycle racers physiological strain would enhance the understanding of potential performance limitations. The only publication reporting physiological strain due to body-heat storage during motorcycle competitions in tropical conditions suggests the riders would benefit from the use of pre-cooling strategies. This study explores such a contention.

Introduction

Riders competing in motorcycle circuit racing perform mainly in summer time, during the central hours of the day, on a dark asphalt surface, wearing a full-face helmet, a full-body leather suit with internal knees, elbows, shoulders, back and chest protectors, boots, gloves, and are aboard a two-wheeled vehicle powered with an internal combustion engine. Given these factors in tandem with the geographical locations of these competitions, national and international championships might represent a challenge in terms of the heat stress experienced by the athlete (D'Artibale et al., 2018b).

Considering the temperatures of the environment surrounding the riders, and the muscular and cardiovascular activities due to the inertial stress of racing, safety equipment most likely restricts body-heat dissipation. While the partial exposure to high wind may seem an evident advantage in dissipation of heat by convection, it must be considered that with the exception of some braking actions and high leaning positions in corners, for the acceleration phases, riders aim at maintaining a position that optimises aerodynamic penetration. Therefore by protecting their impact with high speed air, they minimise the cooling effects.

Previously researchers reported that elite circuit racing riders endured moderate to high physiological strain during practice, qualifying and race sessions due to body-heat storage when competing in tropical conditions (Brearley et al., 2014). Such findings and anecdotal reports suggest that races contested in warm to hot conditions may represent a thermoregulatory threat for the performance of the racers.

Therefore, describing the impact of heat, the efficacy of adopted practices and exploring strategies of pre-cooling to mitigate the negative influences of excessive heat on performance provided the focus of this investigation. This study aims at: 1) quantifying the thermal stress of riders whilst compete in a hot environment and, 2) describing the effect of potential pre-cooling strategies. Understanding these stressors will expand the knowledge and assist in the formulation of action plans to optimise a rider's performance.

Methods

Experimental setting and design

Data were collected during official motorcycle circuit racing competition events (i.e. Italian national championship and the World SuperSport championship), held in dry conditions and with environmental temperatures above 25°C. Both descriptive and comparative designs were implemented for selected physiological and perceptual variables.

Participants

Two male riders holding an international competition FIM license volunteered to take part in this study. Participant A (age 21, body mass 73 kg, stature 1.62 m, body fat 17%), and participant B (age 21, body mass 77.6 kg, stature 1.84 m, body fat 16%) were provided with an information sheet, received full explanations about the protocols, were allowed to withdraw from the study at any time and signed an informed consent form before study commencement. The study procedures were approved by the institutional ethics review board (AUTEC reference number 16/92).

Physiological measurements

Temperatures

Gastrointestinal temperatures were measured with miniature-sized wireless ingestible sensors (i.e. e-Celsius performance capsule from BodyCap, France) swallowed 5 hours before the riding sessions and riders worn a bracelet warning that an MRI result would be invalid. This ingestible core temperature sensor had the ability to collect measurements every 30 seconds using internal memory storage during the riding activity, with data synchronized at a later time using a wireless modality. Before and after the riding, data were stored in an external portable reader (i.e. e-Viewer monitor system from BodyCap, France) and later downloaded for further analysis.

Micro-environment temperatures were measured with miniature-sized sensors placed on skin inside the protective leather suit and inside the helmet (i.e. Thermochron iButton and 1-Wire software from Maxim Integrated Products Inc, California, USA). Micro-environmental temperature was also sampled every 30 seconds and the anatomical sites of measurements were: 1) upper left chest; 2) mid upper left arm; 3) abdominal left side of the navel; 4) mid-point between left scapula and spine; 5) mid left thigh; 6) mid internal side of left calf; and, 7) under the foam layer in the helmet below the occipital region.

Environmental air temperature was recorded with a unit of the same device placed just outside the pit-box in the shade. Environmental relative humidity was measured during the riding sessions with a portable digital weather tracker (i.e. Kestrel 4000, Michigan, USA). Figure 6.1 illustrates the protocol adopted.

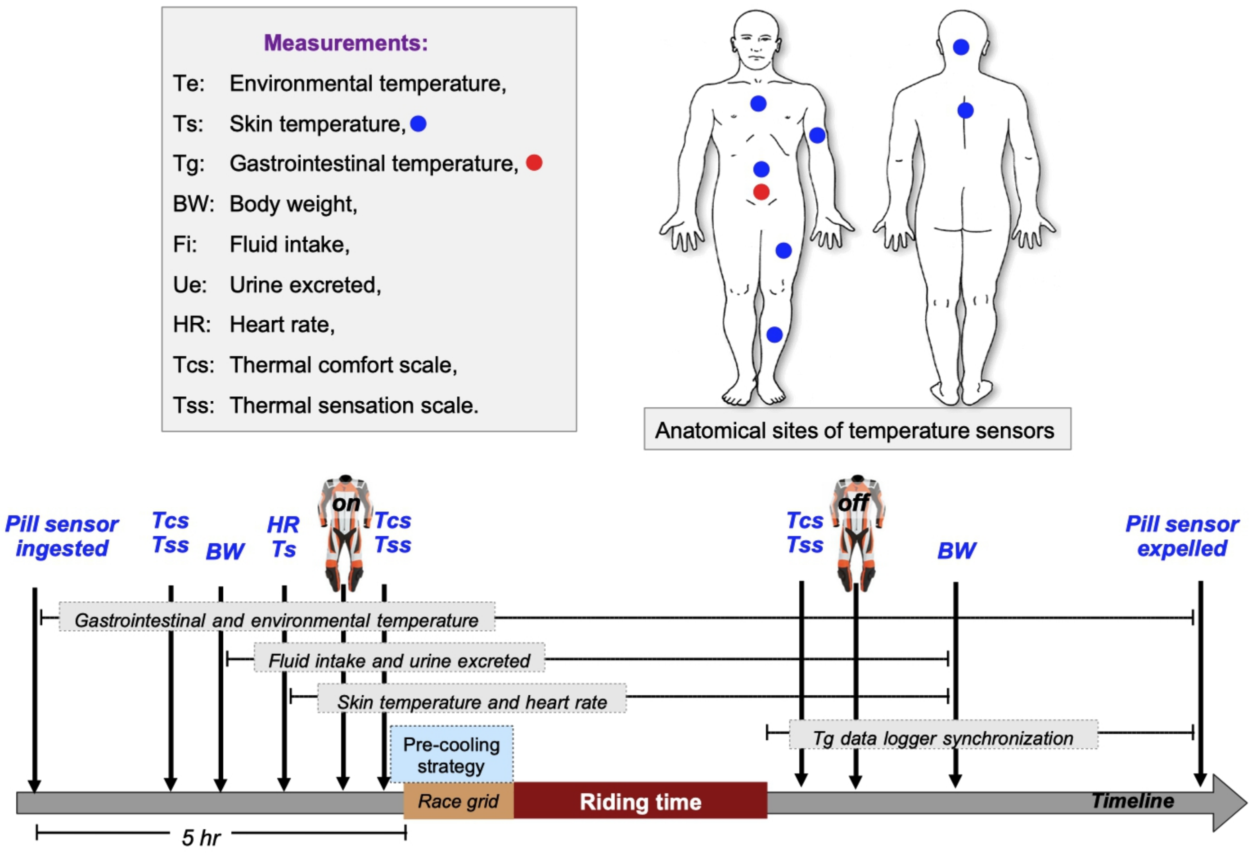

Figure 6.1. List of measurements, map of anatomical sites of measurements and schematic of the experimental protocol used in this study. Sequence and duration of measurements are visualized on a timeline of activities.

Heart Rate

A heart rate monitor with internal memory (Polar Team2, Finland) sampling every 5 seconds was worn under the chest protector for the whole time the rider was equipped with the leather suit.

Fluid balance

Participant's body mass (i.e. riders with dry body wearing only underwear) was measured before and after the riding sessions, with a 50 grams-accuracy body-weight electronic scale (Paula, Korona, Germany). Fluid intake and urine excreted was measured with a 1 gram-accuracy food electronic scale (Kira, Korona, Germany).

Perceptual measurements

Participants were asked to rate their thermal comfort (i.e. How comfortable do you feel with the temperature of your body?) on a 1-to-4 scale and thermal sensation (i.e. How does the temperature of your body feel?) on a 1-to-7 scale (Gagge, Stolwijk, & Hardy, 1967; Schulze et al., 2015). These measurements took place on three occasions: about 1 hour before the riding session, about 15 minutes before the riding session while wearing the protective equipment excluding helmet and gloves, and just after the riding session, as soon as the rider was available.

Pre-cooling strategies

Potential cooling techniques adopted before the riding time were recorded (i.e. cold water consumption, fan exposure, wet towels on skin, crushed-ice ingestion, etc.). When crushed ice ingestion was adopted for pre-cooling, a quantity of 7.5 grams of ice-slurry per kilogram of body mass was available to use (i.e. 550-600 gr), and was well mixed with a small dose of electrolyte supplement providing a carbohydrate content not greater than 5% (Maté, Siegel, Oosthuizen, Laursen, & Watson, 2016).

Data and statistical analysis

In-field data collection was affected by several factors reducing the availability of complete measurements. For example: a) in multiple observations, the data logger collecting gastrointestinal temperatures did not complete synchronization of measurements due to participants' schedule and/or behaviour (i.e. the data logger necessitates to be close to the abdomen for a due time after the riding session); b) sometimes the participants were unavailable to ingest the sensor 5 hours before the riding session and the pill was ingested in advance, however, on a few occasions the pill was excreted prematurely; c) a race was interrupted (i.e. red flag); d) weather conditions changed and a race was declared wet. Also, unpredictable situations (i.e. podium at the end of the race or first row in qualifying or a crash) made it difficult to monitor some parameters such as additional fluid ingested (i.e. champagne, prosecco or additional water/drinks on the podium or in parc ferme', sometimes connected to sponsorship agreements) or made the rider unavailable for collecting perceptual measurements due to the podium, media or medical centre requirements.

Also the record of micro-environment temperatures have encountered limitations due to failure of some instruments during the data collection mission. Moreover, following the export of data from each individual sensor, each set of data required manual separate correction and synchronization. Descriptive statistics (i.e. mean, standard deviation, range) were used to summarise quantitative variables. Differences between methods of pre-cooling were measured in percentages.

Results

Following the completion of a questionnaire investigating the participants' locations, their training and their exposure to heat in the two weeks prior the data collection, the two riders were considered acclimatised to the geographical area of competition.

Given the above mentioned "in-field" limitations, from a total of 20 observations, seven complete files were selected for analysis and comparison; in particular, 3 observations adopted a slushy ingestion combined with a posterior neck pre-cooling strategy, while 4 observations adopted fan, cold water ingestion or wet towel on skin as a pre-cooling, and the results are summarised in Table 6.1. Also, complete profiles of micro-environment temperatures measured with sensors placed on skin inside the protective garments from two of these observations are reported.

	Motorcycle class	SuperSport 600						
	Participant	A				B		
Identity	Sensor	20.00.00.99	20.00.00.99	20.00.06.EF	20.00.03.8D	20.00.01.1A	20.00.01.1A	00.00.28.2F
	Date	July 2016	July 2016	July 2016	July 2016	June 2017	June 2017	July 2016
	Circuit	Misano	Misano	Mugello	Mugello	Misano	Misano	Misano
	Level	National	National	National	National	International	International	National
	Session	Qualifying 2	Race	Race	Race	Warm Up	Race	Qualifying 2
	Podium	no	yes	no	no	no	no	no
Conditions	Mean Air Temp. (°C)	30.9	34.2	33	32	28.2	28.8	29.8
	Air Humidity (%)	46	53	30	44	40	41	60
	Pre-cooling strategy	Fan	Slushy + Gel ice-pack on neck	Slushy + Gel ice-pack on neck	Fan and Wet towel on skin	Fan	Slushy + Gel ice-pack on neck	Cold water consumption
Physiology	Gastrointestinal Temp. Minimum (°C)	37.2	38.1	37.7	37.8	37	38	37.9
	Gastrointestinal Temp. Maximum (°C)	38.7	40.1	39	38.8	38.6	39.3	38.7
	Gastrointestinal Rate (°C/minute)	0.042	0.071	0.045	0.033	0.067	0.041	0.036
	Fluid Loss (kg)	1.75	2.20	1.46	2.20	n/a	1.45	0.73
	% Body Mass Lost	2.40	3.04	1.96	2.95	n/a	1.85	0.95
	Mean Heart Rate (bpm)	166	192	179	186	n/a	177	174
	Peak Heart Rate (bpm)	191	196	189	190	n/a	186	187
Perceptual	Thermal Comfort Pre Suit	1	2	1	1	1	1	2
	Thermal Comfort Pre Riding	2	2	1	1	1	1	2
	Thermal Comfort Post Riding	3	4	1	1	2	3	4
	Thermal Sensation Pre Suit	6	6	6	6	5	5	6
	Thermal Sensation Pre Riding	6	6	5	5	6	6	6
	Thermal Sensation Post Riding	7	7	7	7	7	7	7

Table 6.1. The data-set of thermal stress of two riders during official competitions in hot environments, with the exclusion of micro-climate temperatures inside the leather suit.

Temperatures

Environmental conditions ranged from a minimum of 28°C to a peak of 34.5°C during riding sessions (mean ± SD: 31 ± 2.2°C), while relative air humidity ranged from 30% to 60% (mean ± SD: 44.9 ± 9.6%) . The maximal gastrointestinal temperature was 40.1°C, recorded during a national race where the participant finished on the podium, on the day when also the mean environmental air temperature during the session reached its max: 34.2°C (Figure 6.2). A large relationship (r > 0.5) was found between mean environmental and maximal gastrointestinal temperatures (r = 0.595; CI: -0.29 to 0.93). Over the entire 7 sessions (1 Warm Up, 2 Qualifying and 4 Races), the mean value of maximal gastrointestinal temperature was 39 ± 0.5°C. During riding, the core temperature increased at variable rates, ranging from 0.033°C/min to 0.071°C/min (mean ± SD: 0.048 ± 0.015°C/min).

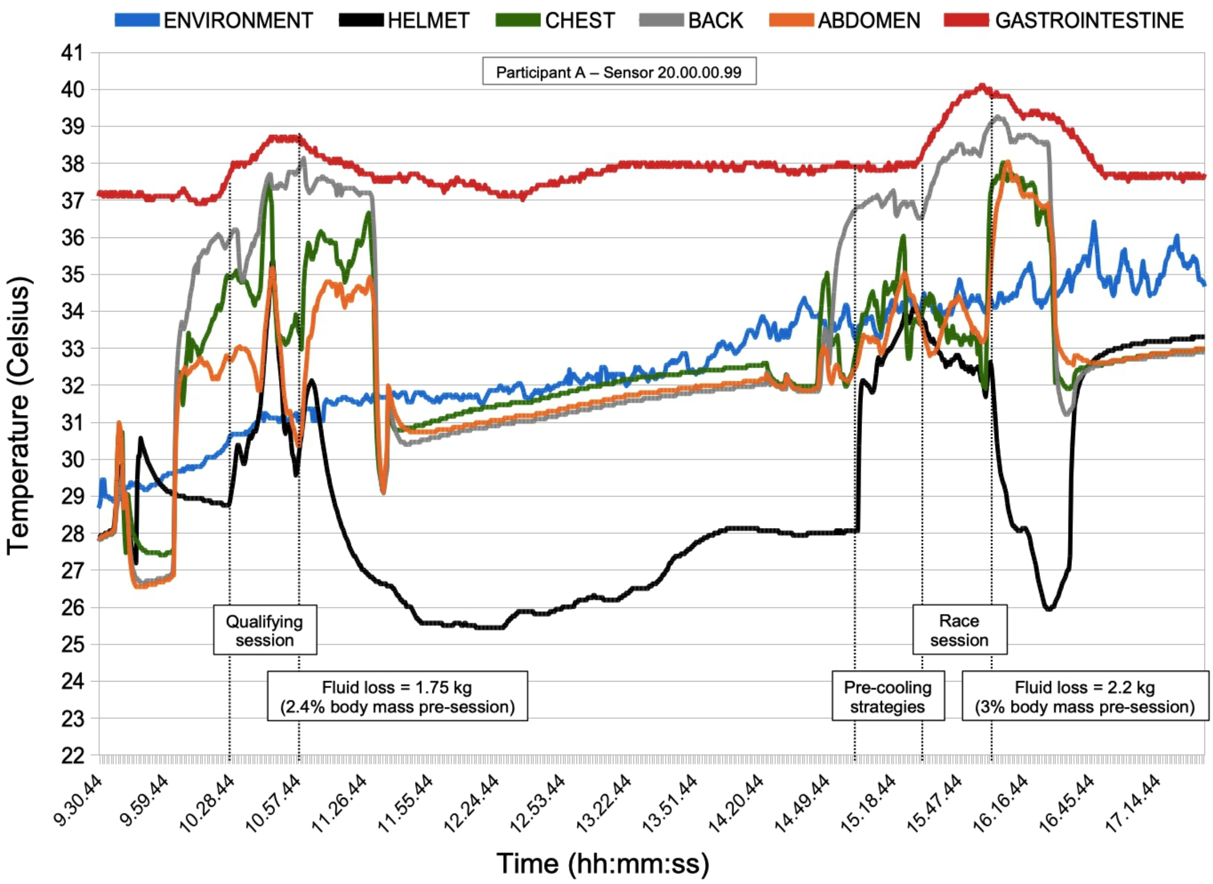

Figure 6.2. Thermal profile of rider including gastrointestinal and micro-environment temperatures inside the leather suit during official competition sessions.

During the riding sessions, the anatomical sites back and arm recorded the highest temperatures, with 38 ± 0.6°C and 35.8 ± 0.2°C respectively recorded during the official race. The calf area also resulted in being a hot site, with 35.2 ± 0.3°C during the race and 34.8 ± 0.8°C during the qualifying session. The accumulation of heat on skin was particularly evident from the measurements recorded during the minutes following the race, where two thirds of the body was above 37°C (Table 6.2). The sensor placed in the occipital region of the helmet, on the other hand, recorded values lower than the anatomical sites inside the leather suit, with temperatures fluctuating around the environmental air values.

		Temperatures (Celsius)								
		ENVIRONMENT	**HELMET**	**CHEST**	**BACK**	**ABDOMEN**	**GASTROINTESTINE**	**ARM**	**THIGH**	**CALF**
10' pre-session	Mean	30.00	28.86	33.52	35.77	32.42	37.01	35.05	33.28	33.76
	SD	0.13	0.05	0.44	0.21	0.20	0.09	0.16	0.06	0.08
30' Qualifying	Mean	30.91	31.01	34.53	36.68	32.53	38.28	35.41	33.63	34.83
	SD	0.28	1.73	1.12	0.98	1.16	0.41	0.63	0.58	0.81
10' post-session	Mean	31.25	31.30	35.75	37.47	33.84	38.28	37.11	36.14	36.76
	SD	0.19	0.76	0.29	0.17	0.79	0.13	0.23	0.79	0.52
10' pre-session	Mean	34.11	33.79	34.20	36.79	34.50	37.98	36.01	35.24	34.85
	SD	0.15	0.21	1.14	0.15	0.38	0.06	0.23	0.29	0.56
30' Race	Mean	34.21	32.74	33.45	37.98	33.57	39.37	35.82	34.23	35.21
	SD	0.24	0.48	0.59	0.59	0.48	0.58	0.17	0.29	0.28
10' post-session	Mean	34.27	30.59	37.20	39.10	36.46	39.84	37.89	36.64	37.16
	SD	0.12	1.42	1.11	0.12	1.42	0.07	0.51	0.83	0.92

Legend	> 34	> 37

Table 6.2. Micro-climate temperatures inside the leather suit and helmet.

Heart Rate, Fluid loss and Perceptual Measurements

Heart Rate was reported to be elevated during riding sessions, with means ranging from 166 ± 20 bpm in Qualifying to 192 ± 4 during a Race, while peaks reached during all riding averaged at 190 ± 3.5 bpm.

Riders' body mass decreased due to fluid loss on average of 1.63 ± 0.5 kg in each riding session, with peaks of 2.2 kg measured after two races. The water loss during riding was on average 2.2 ± 0.8% of the riders' body mass. A moderate relationship ($0.3 < r < 0.5$) was found between the quantity of fluid loss and the maximal gastrointestinal temperature ($r = 0.462$; CI: -0.56 to 0.93).

Regardless of the elevated environmental air temperatures, participants perceived a similar thermal comfort and sensation before and after wearing the leather suit before the performance: 1.29 ± 0.49 was the thermal comfort measured 1 hour before the riding session, and 1.43 ± 0.53 was in the period anticipating the entry on track (1 = Comfortable, 2 = Slightly uncomfortable, 3 = Uncomfortable, 4 = Very uncomfortable); while the exact same value of 5.71 ± 0.49 was recorded for the thermal sensation before wearing the protective equipment and in the 15 minutes before riding the motorcycle (1 = Cold, 2 = Cool, 3 = Slightly cool, 4 = Neutral, 5 = Slightly warm, 6 = Warm, 7 = Hot).

Pre-cooling strategies

When grouping the data according to the modality of adopted pre-cooling, the greatest difference, measured with a percentage of variation, resulted in the gastrointestinal rate, with 17.6% faster increase of temperature in the group of observations where participants ingested ice-slurry and cooled their neck compared to other methods (Table 6.3).

Contrasting results were obtained in the perceptual measurements before and after the riding sessions. While the observations adopting the slushy ingestion and the neck cooling had an 11.1% better thermal comfort before the riding compared to the other strategies, a 6.7% decrement in comfort was recorded after the riding. The thermal sensation instead was slightly better before riding: 1.45% cooler feelings were experienced in the observations using slushy and neck cooling, while it resulted exactly the same in the two groups after the riding, with the value "Hot" being constantly selected in the post session.

Means ± *SD*	Pre-cooling strategy		
	Slushy + Gel ice-pack on neck (n=3)	Other (Fan, wet towel, etc) (n=4)	Δ (%)
Gastrointestinal Temp. Maximum (°C)	39.5 ± 0.6	38.7 ± 0.1	2
Gastrointestinal Rate (°C/minute)	0.052 ± 0.02	0.045 ± 0.02	17.6
Fluid Loss (kg)	1.70 ± 0.43	1.56 ± 0.75	9.1
Thermal Comfort Pre Riding	1.33 ± 0.58	1.50 ± 0.58	-11.1
Thermal Sensation Pre Riding	5.67 ± 0.58	5.75 ± 0.50	-1.45
Thermal Comfort Post Riding	2.67 ± 1.53	2.50 ± 1.29	6.7
Thermal Sensation Post Riding	7 ± 0	7 ± 0	0

Table 6.3. Means and standard deviations grouped by pre-cooling strategies and their difference in percentage.

Discussion

The goal of this study was to quantify the thermal stress of riders whilst competing in a hot environment and also describe the effect of potential pre-cooling strategies that were adopted by riders. The impact of heat on riders was quantified using physiological and perceptual measures, and the main findings were: 1) riders performing in hot conditions experienced internal and external thermal stress, during and immediately after their riding; 2) consequently, they experienced considerable fluid loss during their performance; 3) although pre-cooling strategies such as ice-slurry ingestion and neck cooling provided an improved perceptual status for the beginning of their performance, more research is needed to clarify the effects on the final stages of their racing.

Thermal stress

Independent from environmental conditions, riders are required to wear a full set of safety garments that increase thermal insulation causing more rapid increases in temperature during exercise and imposes a barrier to sweat evaporation (Gavin, 2003). Indeed, we measured that a rider competing at an environmental air temperature of 31 ± 2.2°C and humidity of 44.9 ± 9.6%, experienced a rise of gastrointestinal temperature of 0.048 ± 0.015°C/min - averaged data from qualifying, warm-up session and race. Similarly, Brearley et al. (2014) reported increases of 0.035, 0.037 and 0.067°C/min of gastrointestinal temperature increase during practice, qualifying and race respectively, at a mean ambient temperature of 29.5 - 30.2°C and relative humidity of 64.5 - 68.7%. From the analysis of the data (Figure 6.2), internal peak temperatures were consistently found at the end of the riding sessions (i.e. mean maximal gastrointestinal temperature: 39 ± 0.5°C), with greater values reached at the end of actual racing (i.e. range 39 - 40.1°C in race session), which are in line with performances where continuous effort for prolonged time is required.

Although innovative materials and technological solutions are improving the efficiency and weight of some of the protective equipment (i.e. ventilated helmets; perforated kangaroo leathers with elastic inserts; helmet visor tinting can reduce the actual and perceived heat load on the wearer by reducing the transmission of solar radiation (Buyan et al., 2006)), still the level of protection required against impacts and abrasion represents for riders a substantial limitation in terms of heat loss. This was confirmed from the thermal sensation scores recorded after riding – always "hot" – and from the temperatures recorded measuring the micro-climate inside the leather suit, which were found to be generally hotter than the environmental values before, during and after the riding sessions. Clearly, some anatomical regions less exposed to air convection while riding, such as the posterior area of the torso and the upper arm (temperature range: 35.4 - 38°C), tend to accumulate heat in greater quantities than regions more exposed to ventilation, such as the chest and the abdomen (temperature range: 32.5 – 34.5°C). In addition, while the body portions that exit from the "ideal aerodynamic posture" during braking and cornering, such as the helmet in particular, can benefit from the cooling effect of high speed air convection, others such as the calf in particular, seems to be affected by its proximity to the engine. Interestingly, it has been noticed how some temperatures inside the leather suit rapidly increase during the pitstop and immediately after the race (temperature range: 36.5 – 39.1°C), which is when the rider is still fully equipped, but not exposed to high speed air convection. In some observations (Figure 6.2), also the gastrointestinal temperature was briefly plateauing at its peak after the end of the riding session, perhaps due to the accumulation of both internal and external heat not being counteracted by cooling from convection.

Fluid loss

As a consequence of the reported thermal stress, motorcycle circuit racers can experience considerable sweat production during their riding performance in hot conditions. While Brearley et al. (2014) quantified the sweat rate at 0.95 L/h in qualifying and free practice, resulting in a 1.2% body mass loss, in this study including 4 races, immediately after the riding sessions, the rider's body mass was found to be 2.2 ± 0.8% lighter due to the fluid loss. Despite the longer duration of free practice sessions, peaks of 2.2. kg of fluid loss were measured on two occasions after official races; and riders' body mass decreased on average 1.63 ± 0.5 kg in each riding session.

Pre-cooling strategies

The combined external and internal pre-cooling interventions have been reported to improve thermal sensation prior to the commencement of exercise, resulting in improvements in performance and mental concentration (Ross, Abbiss, Laursen, Martin, & Burke, 2013). In this study, the combination of ice-slurry ingestion with cooling the posterior region of the neck with an ice-gel pack on the starting grid were tested in comparison to other pre-cooling methods such as the use of a fan, cold water consumption or a wet towel on skin before riding. The ingestion of an ice-slurry has been suggested to be effective (Siegel et al., 2010) and provide an alternative strategy for inducing a similar magnitude of internal cooling from a smaller volume of ingested beverage (Ross et al., 2013).

Results indicated that this pre-cooling strategy (i.e. ice-slurry + neck cooling) applied just before the start of a race improved the initial thermal status and feelings of the rider, but no physiological measurements reflected such perceived benefits. The thermal sensation and comfort were cooler in this group, and participants declared to appreciate such pre-cooling practice, stating that "Ice in mouth during the grid of the race gives you that kick of freshness that keeps your eyes open". However, interestingly the thermal comfort post-riding and the internal temperatures were greater; in fact, both the maximal gastrointestinal temperature and its rate of increase were found greater in the group where the slushy ingestion and neck cooling were applied (Table 6.3). The reader needs to be cognizant, however, that while the slushy group data was from three races, the other group values were from two qualifying, one free practice and one race. Usually, the race is the session considered most physically demanding (D'Artibale et al., 2008; D'Artibale et al., 2017) and higher exercise intensities would result in increased internal temperature (Montain, Sawka, Cadarette, Quigley, & McKay, 1994) and higher sweat rates (Gavin, 2003).

Approaches that can reduce initial body temperature prior to exercise, or attenuate the rate of heat gain during exercise, have been shown to increase the time it takes to reach a critical limiting temperature and thus prolong exercise performance (Gonzalez-Alonso et al., 1999). However, considering the limited data sample and the lack of a strong comparative experimental design (i.e.

influence of the intensity of different riding sessions), more data will be needed to clarify the potential benefits of such pre-cooling strategies on the later part of the motorcycle racing performance.

Limitations

Although this study attracted interest from several participants and managers, finding volunteers available to be measured under real competitive conditions was difficult, as typical of research in motorcycling (D'Artibale et al. 2018b). Despite the limited sample size, this study offers an insight of the internal and superficial temperatures riders experience in official national and international competitions held in hot environment, analyzing also the responses to a pre-cooling practice.

Conclusion

Performing in a full leather suit, during the central hours of a summer day, aboard an internal-combustion-engine vehicle provides a serious thermoregulatory challenge to riders. Motorcycle circuit racers are exposed to internal and external heat, only partially mitigated by the magnitude of the high speed air conduction while riding. The accumulation of heat was particularly evident at the end of the race, when both the gastrointestinal and micro-climate temperatures attained peak values. Consequently, riders experienced elevated sweat rate and are therefore required to be prepared in coping with dehydration.

The ingestion of ice-slurry combined with neck cooling as a pre-cooling strategy immediately before the racing performance received positive perceptual feedback from riders, however physiological measurements do not clarify the utility of such pre-cooling methodologies. Therefore, even though this pre-cooling strategy sounds promising, more research is needed to validate its efficacy. It is evident that in a sport like motorcycle circuit racing, some cooling or pre-cooling techniques for the athlete can be logistically challenging or impractical for use in competition, nevertheless, future research supported by the forefront technology available in motorsports, could provide solutions to reduce the negative influences of excessive heat on human performance.

To be prepared for competitions in hot environments, riders need to be well planned to become acclimatized and practiced in hot conditions and therefore develop heat tolerance. In addition, adopted protective equipment should be designed to minimize heat accumulation and undergarment clothing should be carefully selected and tested for the same purpose. It would be essential that riders adopt an efficient hydration plan for the racing event, and have a plan of action that aims at keeping their body hydrated and cooled before - and if possible during - the performance (i.e. hump-to-helmet hydration systems).

Chapter 7 – Measure of psychological skills via TOPS2 in motorcycle circuit racing riders.

This chapter is presented in a *Brief Report* version (to be published).

Author contribution: D'Artibale E: 90%; Cronin JB: 10%

Prelude

The multidisciplinary approach adopted to answer the thesis overarching question, has so far provided information on the mechanical and physiological demands of racing motorcycles. Data suggest that among the complex interaction of specific skills and abilities, riders are required to cope with a number of stresses during competitions. Considering these stresses and the risk of injury involved in racing, an investigation focusing on the psychological component of this sport would enhance and complete the "understanding the rider's performance" section (Figure 1.1). In fact, although the psychological attributes of a rider being reportedly significantly influential in riding performance, very few publications have profiled this quality within motorcycle racers. Instruments targeting psychological skills and strategies in sport are likely to differentiate more and less successful athletes and provide evidence regarding the efficacy of psychological skills training programs. Through the use of a validated self-report instrument (Test of Performance Strategies), this study explores the psychological skills used by riders in both practice and competition settings.

Introduction

Races in motorcycle circuit racing are fierce competitions wherein a multitude of riders battle with each other in a high-risk, high-cost sport (D'Artibale et al., 2018b; Pedersen, 1997). The specific characteristics of the racing performance, at higher competitive levels in particular, suggest that riders are required to manage cognitive-emotional stress and therefore the involvement of psychological factors on performance outcome seem to be substantial (Dosil & Garcés de Los Fayos, 2006). Despite the popularity of the sport, the magnitude of the financial resources invested into the development of the motorcycle performance, and the proven association between psychological variables and performance outcome in other sports, the study of the psychological component in motorcycle circuit racing is extremely rare in the scientific literature.

A case study (Jevon & O'Donovan, 2000) reported an intervention program on an injured national-level rider as successful in improving motivation and confidence in returning to competition. A variation of Butler's performance profile (1992) was used to determine areas of importance, and intervention strategies consisting of a combination of relaxation techniques, imagery, positive self-talk and affirmations, goal setting, negative thought stopping and cognitive restructuring were gradually introduced to the racer over 12 appointments by the athletic trainer after consultation with the sport psychologist.

Differently from such integrated individualised rehabilitation process, a program of 2.5 months of physical, technical and tactical training appeared to have unclear effects on the psychological status of young elite riders (n=16; mean age 15.6 years) (Mateo-March et al., 2013). While experts' subjective evaluations of psychological responses to competitions indicated improvements, and post-intervention completion of 10-item Perceived Stress Scale (PSS-10) was found to be reduced, no significant differences were reported in self-evaluated physical and psychological status, along with no variations in self-esteem as measured with the 10-item Rosenberg scale. Despite such an investigation not describing specific constructs or psychological traits as in the case study (Jevon & O'Donovan, 2000), the study does offer a specific insight of the context, shaping an experimental intervention program with a multidisciplinary approach (Mateo-March et al., 2013).

The only publication describing a personality construct in professional motorcycle racers reported the assessment of hardiness, the personality characteristic anticipated to explain the differences in mood states among individuals who are subjected to stress (Thomas et al., 2013). They reported that the top 10% of elite riders recorded a significantly higher hardiness mean score than the bottom 10%, perhaps indicative of their ability to appraise and cope with competitive challenges, with behaviours linked to the attitudes of control, commitment and challenge.

These types of analyses would seem informative in terms of talent identification or in the guidance of athlete development programs, given a well-rounded psychological profile of riders would help establish a baseline for monitoring the status of mental skills, guide potential intervention/training programs and in term positively influence performance. Along with the objective of providing participant riders with free individual psychological reports, the aim of this study was to quantify the psychological skills and strategies used by motorcycle circuit racing riders in competition and during practice, and explore potential relations or differences according to their success rate.

Methods

Experimental Design

Participants were invited to complete anonymously an online self-report questionnaire away from competition events. Potential participants were initially invited to participate with an email or message on social media, in which information and procedures about the study were detailed. Once they replied expressing interest and willingness to participate, a link to the free online questionnaire was sent. No name was asked when completing the questionnaire, however, participants had the choice to enter an email address before submitting the answers, so they could receive a report summary sheet describing the constructs being targeted together with their own profile (Appendix C). Responses from participants were collated and analysed.

Participants

Federation-licensed riders aged between 16 and 50 years old were invited to take part in this study. Potential participants were identified through the consultation of official race reports, other competitive riders or the use of internet. Only active riders (competing in official motorcycle circuit racing events in the last 12 months) were included in the analysis. About 100 riders were individually invited to participate to this study, and two native English-speaking national Motorcycling Federations were contacted in the attempt to enlarge participant recruitment. Ten complete questionnaires were collected, from male (n = 9) and female (n = 1) riders. Participants (age 20.5 ± 3.6 years) were from England, Estonia, Germany, New Zealand, Norway, South Africa, and United States of America, and 8 of them declared English as their native language. They had 9.8 ± 4.5 years of motorcycle competition experience, and all of them except from one had exposure to international level racing.

The research protocol was reviewed and approved by the Auckland University of Technology Ethics Committee, reference number 15/330.

Instruments

Riders were invited to answer a 64-item questionnaire instrument (i.e. Test of Performance Strategies - TOPS2 by Hardy, Roberts, Thomas & Murphy 2010) choosing responses on a 5-point

Likert scale ranging from 1 (never) to 5 (always). This validated tool was designed to measure a comprehensive range of psychological skills and techniques used by athletes in competition and at practice (Hardy, Roberts, Thomas, & Murphy, 2010). The eight classified subscales in competition were: self-talk, emotional control, automaticity, goal setting, imagery, activation, relaxation, and negative thinking. The same skills were classified at practice, with the difference that the subscale attentional control replaced the negative thinking construct. Questionnaire was designed and delivered with shuffled questions, therefore participants were not instructed about which 4-set of questions defined the 16 subscales being targeted.

Before starting the online questionnaire, participants also completed a brief athlete-background form and declared to have read and understood the initial information sheet, along with accepting the consent form to take part into the study. At the top of every page of questions, participants were instructed that the term practice was referring to training sessions, official free-practices and warm-up sessions; while the term competition was referring to qualifying sessions and races.

Data and Statistical Analysis

Results were exported from the website to a spreadsheet, and R software was used for analysis. Scoring was assigned on a reverse scale in the items with a negative factor loading (Hardy et al., 2010). Descriptive statistics (i.e. mean and standard deviation) were used to describe the eight subscales (i.e. goal setting, relaxation, activation, imagery, etc.) and compare them with results of athletes from different sports from previous publications. Pearson correlation coefficient (r) and its 95% CI using Fisher's z transform was used to explore potential relationships between psychological subscales and background information (i.e. years/level of experience, titles, etc.). Trivial, small, moderate, large and very large relationships were considered for r between 0 and 0.1, 0.1 to 0.3, 0.3 to 0.5, 0.5 to 0.7, and larger than 0.7, respectively (Hopkins et al.,, 2009). Data sample was sorted according to the titles awarded to riders in their career and two equal groups were considered for comparison: top-ranked title winners vs bottom-ranked title winners. Percentage and standardized difference in means were used to compare subscales' scores between groups. Trivial, small, moderate, large and very large differences were considered for standardized difference in means between 0 and 0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2, and larger than 2, respectively.

Results

All the participants considered circuit race motorcycling their main sport. The subscales' means and standard deviations in competition and practice can be observed in Table 7.1, where the results from other sports cohorts are also presented. The lowest scores were collected in relaxation at practice (2.03 ± 0.85) and negative thinking in competition (2.33 ± 1.02). Conversely, the most frequently used skill was automaticity both in practice (4.05 ± 0.45) and competition (4.18 ± 0.60).

The strongest association between the psychological skills/techniques and the variables quantifying the riders' experience/background was found between the relaxation in competition (r = 0.80; CI: 0.34 – 0.95) and at practice (r = 0.74; CI: 0.21 – 0.93) with the amount of races that a rider had accumulated during his/her career at the time of the questionnaire. Also, the number of races that participants had competed in resulted in large correlations to competition subscales self-talk (r = 0.69; CI: 0.11 – 0.92) and imagery (r = 0.67; CI: 0.08 – 0.92). Additionally, activation in competition was negatively related to the titles won by riders (r = -0.64; CI: -0.91 – -0.02).

	Practice							
	Emotional Control	**Activation**	**Relaxation**	**Self-Talk**	**Goal Setting**	**Imagery**	**Automaticity**	**Attentional Control**
Riders Motorcycle Circuit Racing (n=10)	3.13 ± 1.11	3.30 ± 0.72	2.03 ± 0.85	2.75 ± 0.96	3.85 ± 0.49	3.13 ± 0.76	4.05 ± 0.45	3.48 ± 1.04
Normative data from different sports (n=565) (Hardy et al. 2010)	3.42 ± 0.76	3.41 ± 0.63	2.18 ± 0.83	3.35 ± 0.80	3.24 ± 0.89	3.02 ± 0.82	3.47 ± 0.65	3.44 ± 0.66
Amateur road racing car drivers (n=55) (Morgan, 2013)	3.77 ± 0.66	3.46 ± 0.58	2.12 ± 0.88	2.98 ± 0.91	3.65 ± 0.64	3.36 ± 0.77	NA	3.68 ± 0.55
US medalist at Sydney Olympics (n=52) (Taylor et al. 2008)	3.61 ± 0.59	NA	2.49 ± 0.98	3.66 ± 0.64	3.54 ± 0.88	2.95 ± 0.86	NA	3.69 ± 0.55
	Competition							
	Emotional Control	**Activation**	**Relaxation**	**Self-Talk**	**Goal Setting**	**Imagery**	**Automaticity**	**Negative Thinking**
Riders Motorcycle Circuit Racing (n=10)	3.43 ± 0.93	3.75 ± 0.75	2.73 ± 0.98	2.93 ± 0.91	3.93 ± 0.55	3.33 ± 0.80	4.18 ± 0.60	2.33 ± 1.02
Normative data from different sports (n=565) (Hardy et al. 2010)	3.69 ± 0.83	3.84 ± 0.70	2.80 ± 0.94	3.42 ± 0.86	3.73 ± 0.86	3.49 ± 0.94	3.52 ± 0.63	2.23 ± 0.77
Amateur road racing car drivers (n=55) (Morgan, 2013)	4.15 ± 0.65	3.41 ± 0.69	2.65 ± 0.80	2.9 ± 0.99	3.86 ± 0.80	3.24 ± 0.91	NA	1.88 ± 0.57
US medalist at Sydney Olympics (n=52) (Taylor et al. 2008)	4.02 ± 0.52	3.92 ± 0.64	3.83 ± 0.60	3.71 ± 0.82	3.94 ± 0.81	3.59 ± 1.07	3.44 ± 0.73	1.91 ± 0.51

Table 7.1. Means and standard deviations of TOPS2 subscales of motorcycle circuit racers along with results from previously published articles.

When splitting the results between the top-ranked and the bottom-ranked title winners, the mean scores of 6 subscales in competition (i.e. emotional control, activation, goal setting, imagery, automaticity and negative thinking) and 4 subscales in practice (i.e. activation, relaxation, goal setting and imagery) were scored lower in the top-ranked title winners as compared to the less successful group (Table 7.2). In particular, the subscale imagery in practice was 13% lower in the top-ranked title winners group (considering the score 5 the 100% of the Likert scale) and the standardized difference in means was moderate (0.91). Similarly, activation in competition (12% difference) and goal setting both in practice (12%) and competition (11%) were scored greater in the bottom-ranked title winners group. The standardized difference in means between the top-ranked and the bottom-ranked title winners was large in goal setting at practice (1.65) and moderate in the same subscale during competition (1.18).

	Practice							
	Emotional Control	Activation	Relaxation	Self-Talk	Goal Setting	Imagery	Automaticity	Attentional Control
Δ (%)	3	-2	-1	2	-12	-13	2	5
Stand Diff Means	0.13	0.13	0.06	0.10	1.65	0.91	0.21	0.23

	Competition							
	Emotional Control	Activation	Relaxation	Self-Talk	Goal Setting	Imagery	Automaticity	Negative Thinking
Δ (%)	-1	-12	3	3	-11	-9	-1	-1
Stand Diff Means	0.05	0.84	0.15	0.17	1.18	0.56	0.08	0.05

Table 7.2. Differences between the top-ranked and the bottom-ranked title-winners groups.

Discussion

This unique investigation aimed at quantifying the use of psychological skills and techniques in motorcycle riders during competition and at practice, and subsequently, exploring potential relationships with riders' experience and achievements. Extensive research has demonstrated that the strategic use of mental skills is a fundamental requirement for sport peak performance (Williams & Krane, 2001; Taylor, Gould, & Rolo, 2008). In motorcycle circuit racing, the injury-risk factor along with the financial requirements of this sport might represent an additional psychological stress for riders, therefore monitoring the use of psychological skills can be of high importance in assisting the performance (D'Artibale et al., 2018b).

Moreover, since competitive conditions are impossible to replicate in training and the out-of-competition riding sessions may not offer technical specificity (i.e. different track, motorcycle, conditions, etc.), assessing the use of psychological skills and techniques at practice may be of guidance for the racers' preparation programs. Given this brief, the main findings of this study were: 1) compared to other sports and Olympic medallists, motorcycle riders scored lower emotional control both at practice and in competition, along with higher negative thinking and automaticity; 2) riders' use of relaxation techniques, self-talk and imagery increases with racing experience; and, 3) surprisingly, riders with a more successful background, recorded lower scores in the majority of psychological subscales.

While riding, a rider needs to make quick decisions and subsequently act with precision; obviously anxiety or other negative emotions do not help fine performing, creating confusion, uncertainty and early fatigue. Fletcher and Hanton (2001) reported that athletes who made high use of relaxation, self-talk, and imagery skills differed significantly in their competitive anxiety responses from those who made low use of these psychological skills. Considering the score riders collected in these subscales (Table 7.1), along with the score recorded in negative thinking (i.e. the highest among the other populations of athletes), and the means of emotional control (i.e. the lowest both in practice and in competition), it may be assumed that the limited sample of participants struggled with coping strategies in relation to the magnitude of the psychological stress they were experiencing with the sport. This assumption, combined with the high-speed executions and the repetitive movements required in circuit racing, may explain why the riders' scoring of automaticity, both in practice and in competition, was the highest in the whole profile and higher compared to the available data from other sports (Table 7.1).

Riders' use of psychological techniques helpful in managing the stresses of the racing performance appeared to be increasing with racing experience. The use of relaxation techniques, both in competition and at practice, resulted in a large correlation with the amount of races that riders have accumulated in their career. In a thrilling sport such as motorcycle racing, the ability to manage the tension and emotions during the competitive sessions is considered vital for performance. Indeed, the high-speed maneuvers, the risks embedded with racing, and the pressure of external factors such as sponsors or financial requirements can magnify the tension and increase the likelihood of mistakes. Moreover, it must be considered that competitive events last three days, therefore varying intensities of anxiety can be experienced around the performances during the different sessions (i.e. free practice, qualifying, racing) (Dosil & Garcés de Los Fayos, 2006). Despite the use of relaxation techniques as a coping strategy seems to be a natural necessity in such a competitive environment, participants in this study recorded the lowest score in the relaxation subscale at practice. In comparison, their mean values at practice and competition were similar to the scores recorded from amateur road racing car drivers (Morgan, 2013), but was substantially lower than the use of relaxation in competition settings reported for American Olympics medallists (sport of medal not specified) (Taylor et al., 2008).

Additionally, the use of self-talk and imagery increased with racing experience. No publications have verified the effects of imagery in motorsports, however from interviews and live broadcasting, performing visualization techniques immediately before the riding sessions appears to be popular among professional riders, since they are used to virtually riding the track layout in order to establish an optimal arousal state in anticipation of the real performance. Visualization/imagery techniques allow riders to mentally rehearse the riding actions on track, and give them the opportunity to analyse, reflect and eventually work on some physical, technical and psychological stimuli without actually getting on the motorcycle (Dosil & Garcés de Los Fayos, 2006). In this study, the use of imagery in competition was found similar to other sports (Table 7.1) and surprisingly, the mean value of the imagery subscale was 13% lower in practice and 9% lower in competition in the participants top-ranked in the title-winners ranking list (Table 7.2). While this result seems to discourage the use of imagery, the scores recorded in competition largely correlated to the number of races that participants had competed in, perhaps suggesting that riders integrate this technique in their routine with competitive experience.

Unexpectedly in this study, when results were split between the trophy winners and the less successful participants, riders with more wins recorded lower scores in the majority of psychological subscales. In particular, despite riders scoring highly in goal setting both at practice and in competition, a large standardized difference in means was found in goal setting at practice and moderate at competition, with the most successful riders making lower strategic use of this skill: 12% less at practice and 11% less in competition (Table 7.2). Such differences are surprising in a multifactorial sport such as motorcycle racing, where mastering the ability to set specific targets and progress through measurable steps is known to facilitate the work and improve its efficiency.

Previously researchers identified the top 10% of elite motorcycle riders (n=32) having a significantly higher mean score in the personality construct of hardiness (Nowack's Cognitive Hardiness Inventory, 1990) than the bottom 10%, perhaps indicative of their ability to appraise and cope with competitive challenges, with behaviours linked to the attitudes of control, commitment, and challenge (Thomas et al., 2013). This study did not assess hardiness as such, but the fact that more successful riders reported less use of psychological skills in 10 out of 16 subscales, may highlight that the interactive effects of psychological skills usage with either personality or situational factors are still unclear (Hardy et al., 2010). It is believed that data from a larger sample size would be necessary to both define normative profiles for motorcycle riders, and clarify the relationships between the use of performance strategies and success/experience in motorcycle racing.

Conclusion

The TOPS2 from Hardy et al. (2010) is an instrument for measuring the use of psychological skills in practice and at competition; its application in motorcycle racing could be valuable in assisting riders to improve the quality and specificity of their development programs. In this study, riders reported high skill level in automaticity, high use of goal setting and low level of emotional control compared to published data from other sports. Also, the high score found for negative thinking, associated with limited use of relaxation and imagery techniques, implies that the limited sample of participants struggled with coping strategies in relation to the magnitude of the psychological stress they were experiencing. Riders' use of relaxation, of imagery in competition and the level of self-talk in competition was shown to increase with racing experience, while surprisingly, in 10 out of 16 subscales more successful riders reported less use of psychological skills.

Cognizant of the limited sample size, this study offers an initial analysis of the strategic use of some psychological aspects in motorcycle racing. It would seem that riders could benefit greatly from interventions addressing the psychological components of performance, however more research is needed to clarify the relationships between the use of performance strategies and success or experience in motorcycle racing. Certainly, the integration of instruments monitoring the psychological skills can be a valuable support in a rider's career and future studies focusing on the psychological demands of motorcycle racing would enhance the knowledge on the human factors in such a high-risk, high-cost sport.

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Chapter 8 – Preparation practices of riders competing in motorcycle circuit racing in two different continents.

This chapter is presented in a *Brief Report* version (to be published).

Prelude

The thesis path provided a well-rounded overview of the performance components in motorcycle circuit racing, and so far, framed together a group of studies with the collective purpose to increase the understanding of the rider as a holistic athlete. Indeed, the preliminary quantification of the racing performance parameters (Chapter 2 and 3), alongside profiling the physical load and measuring the inertial stresses (Chapter 4 and 5), suggested that the physical demands of competitive motorcycle racing should not be underestimated. In addition to the mechanical load due to fast riding, a quantification of the temperatures impacting the body during official races in hot environments, in conjunction with potential strategies to mitigate such physical/physiological stressors, informed us that riders need to be prepared to deal also with heat exposure while performing (Chapter 6). To complete the "understanding the rider's performance" section, some psychological skills, which are believed to be influential for optimising performance, were profiled in a small population of riders (Chapter 7). This excursus informed us that a complex combination of physical, technical and mental skills is required to perform in motorcycle circuit racing competitions. Although it may be assumed that such performance requires riders to be committed to a specific training regimen, the scarce literature available on the topic suggests that more information is needed to explain how this population of athletes face preparation for competitions. Therefore, in light of the performance components analysed so far, this closing chapter aims at "profiling current approaches to preparation", by investigating the activities that riders adopt to meet the demands of their sport.

Introduction

The importance of training methods on performance and the influence of their specificity on athletes' development programs are well established concepts in the competitive sport industry. Indeed, monitoring the training load and meticulously refining the characteristics of practice sessions support the optimisation of athletic and cognitive performances in sport (Soligard et al., 2016).

The demands of motorcycle circuit racing suggest that professional programming for riders' preparation to competitions would be a prerequisite to successful performance (D'Artibale et al., 2018b); however, very few studies have described how and how much this population of athletes prepare to race. A worldwide selection of young riders (n = 27, mean age 15.3 years) competing internationally in an entry-level category during the 2009 season and a population of female riders (n = 18, mean age 25.8 years, 2013 season) were reported to have a poor approach to preparation practices (Martin et al., 2015; Rodriguez-Perez et al., 2013). According to these investigations, despite 88% of international young male racers considered physical training essential to improving their performance during competitions, only 27% of them reported using a coach or trainer for programming their preparation, and so did 33% of the female racers taking part at the 2013 FIM female training camp (Martin et al., 2015; Rodriguez-Perez et al., 2013). In particular, the interviewed riders reported: there was little specificity in training; a lack of mental and tactical training sessions; and, trivial support or professional guidance to which riders could benefit from in regards to their human and athletic development.

In the historical records of world-level Grand Prix and Superbike racing, Italian riders are among the most successful athletes in the motorcycle circuit racing discipline (Haefliger, 2016), therefore it has been assumed that an efficient approach to competition has been developed at national championships. Despite the remarkable level of passion and tradition for motorcycle circuit racing in New Zealand, very few Kiwi riders are currently competing at the top level of the sport; therefore, to better understand preparation methods and approaches to competitions, the aim of this study was to describe how New Zealand and Italian licensed motorcycle circuit racing riders currently prepare for racing events.

Methods

Design and methodological approach

A cross-sectional descriptive design was used in this investigation, where racers were invited to complete a free, anonymous, online survey collecting information on their preparation practices and approaches to competitions. Data were collected from two cohorts of riders competing in different continents (i.e. New Zealand and Italy) during the 2016 and 2017 racing seasons.

Recruitment

During the 2016 racing season, Motorcycling New Zealand (MNZ) endorsed the study by inviting via email all the affiliated members to take part in this study. An email with a brief introductory message and the link to participate was sent to all MNZ riders, and two reminders were sent after 30 and 60 days from the first invitation. Due to the lack of endorsement from the Italian Motorcycling Federation (FMI), during the 2017 racing season, riders competing in the Italian motorcycle circuit racing national championship (namely Campionato Italiano Velocitá) were individually and randomly recruited in the paddock during two separate racing events (i.e. total 8 days) and were invited to participate.

Participants were provided with a fully detailed information sheet, declared their willingness to participate at the opening page of the online survey and were allowed to withdraw from the study at any time. To be included into the analysis, the following three criteria were required to be satisfied from participants: 1) Being a rider holding a valid license to compete at any level in road racing, issued from a national or international motorcycling Federation recognized by the Fédération Internationale de Motocyclisme (FIM); 2) Having competed in at least one circuit racing competition with a two-wheel motorcycle in the last 12 months; 3) Having between 13 to 70 years of age.

The research protocol was approved by the institutional ethics review board (AUTEC reference number 15/327).

Participants

In New Zealand, 147 licensed riders (NZ: age 43.9 ± 13.5 years; 93.9% males, 5.4% females, 0.7% third gender; with 9.0 ± 7.9 competitive seasons background) participated to this study, while in Italy, 86 licensed riders (ITA: age 21.7 ± 7.6 years; 96.5% males, 3.5% females; with 9.7 ± 5.3 competitive seasons background) completed the survey satisfying the inclusion criteria.

Survey

Participants were invited to anonymously complete a free online survey organised in five focus areas, totalling a maximum of 38 questions, and taking approximately 15 minutes to complete. Only drop down boxes and select/check boxes were the type of questions included in the survey. The investigation was delivered by a professional online survey service (i.e. Google Forms).

The five sections in the survey collected information about: 1) Riding skills training (with the motorcycle); 2) Physical training (without the motorcycle); 3) Mental training (without the motorcycle); 4) Injury prevention practices; and, 5) Demographic and career profiles. Per each kind of training (i.e. riding, physical and mental), the opening question of the relative section investigated if the participant prepared to compete or practiced using any of that training. In the case of an affirmative answer, the "how", "how often" and "with who" were investigated in each section, with pop-up lists offering multiple specific choices in each sub-section. Also, individually for each of the three types of training and the injury prevention practice, the subjective importance of such activities for success in competition was quantified with a five-point Likert scale from 'Very Important' to 'Unimportant'.

In the injury prevention section, another five-point Likert scale from 'Always' to 'Never' was used to collect information in regards to the frequency of preventative behaviours such as performing body warm-up before competitions, using earplugs during competitions, performing muscular stretching or practicing crash-skills training during preparatory sessions. In addition, the incidence of suffering from the forearm compartment syndrome was assessed among riders with a five-point scale from 'Yes, indeed I have had surgery to reduce the forearm pressure', to 'I have never experienced acute tension, pain and sensory deficit in my forearms'.

In the mental training section, an additional question measured how often riders listened to music before the race to modulate their level of arousal (i.e. anxiety, motivation, stress, etc.); while in the physical and riding-skills training sections additional questions assessed the level of specificity of training programs (i.e. is your program designed specifically for your motorcycling discipline demands such as specific movement patters and peculiar energy demands, and, do you methodically practice specific technical aspects such as braking, cornering, lines, etc. within dedicated sessions, respectively). The demographic section profiled age and sex along with nationality of motorcycling Federation issuing the rider license, whilst the career profile detailed years of competitions, quantity of races and competitive seasons, frequency at different level of competition, titles won, category of current competition, and, if the participant currently competed in any other sport.

The list of questions was reviewed and approved after revisions by an internal institutional panel of three Professors in sport sciences, and the online survey was pre-tested with a cohort of five PhD candidates which provided feedback on online format and functionality. The survey was originally formulated in English, then it was separately translated to Italian from two mother-tongue researchers in sport sciences with experience in surveys; the outcomes were compared and potential differences were discussed and addressed.

Statistical Analysis

Distributions of occurrence, percentages and descriptive statistics were used to summarise collated data and describe the preparation practices of groups of racers. Differences between groups in regards to negative or affirmative answers to practicing training were explored using the Chi-square test on counts data, considering 0.05 as the probability of exceeding the critical value.

Results

Due to the different mean age of the two populations under analysis, to provide an additional standardized comparison between data, a third subgroup of riders was identified, labelled as NZY. This third subgroup included only New Zealand riders below the age of 30 (NZY sample size = 31; age 22.6 ± 3.9 years; 87.1% males, 12.9% females; with 3.8 ± 2.9 competitive seasons background) (Table 8.1).

		Sample size	Mean Age (years)	SD Age (years)	Male (%)	Female (%)	Third (%)
Italian riders	ITA	86	21.7	7.6	96.5	3.5	0
Kiwi riders	NZ	147	43.9	13.5	93.9	5.4	0.7
Subgroup of NZ, riders below the age of 30	NZY	31	22.6	3.9	87.1	12.9	0

Table 8.1. Sample size, age and sex of groups of participants.

Due to the list of questions (n=38) and relative answer options, a great amount of detailed results were produced, and the 16 tables attached to this script provide full and comprehensive description of recorded variables. The percentages in the tables refer to each population of participants, and not always the sum of percentages equals 100: for example, the sum of the different techniques of mental training adopted by riders would be only equal to the portion of riders that answered "yes" to mental training. Here below, a summary of main results is presented organised in five sections.

Riding skills training

Although riding skills training was considered the most important for success from riders (93% of "very important" and "important"), about one out of five interviewed riders declared to not practice it in preparation to performance (78 – 84% of "yes" practicing riding; $\chi^2_{(1)}$= 1.03; p > 0.05) (Table 8.2).

	Riding Training		How it is considered from riders (%)				
	Yes (%)	No (%)	Very Important	Important	Moderately Important	Of Little Importance	Unimportant
ITA	84	16	**83**	14	3	0	0
NZ	78	22	**71**	18	10	0	1
NZY	84	16	**77**	19	3	0	0

Table 8.2. Percentage of riders practicing riding the motorcycle and perceived importance.

"Riding on asphalt circuits" was the most frequently used method of riding-skills training (53.1%), but Italian riders also used "Motocross" and "Supermotard" (11.6 – 33.7% range) and New Zealand racers used riding "off-road or Enduro" (12.2%) (Table 8.3).

Riding Training		How often riders (%) Always	Very Often	Sometimes	Rarely	Never
Riding on asphalt circuits	ITA	16.3	31.4	15.1	8.1	12.8
	NZ	27.2	31.3	16.3	2.0	1.4
	NZY	29.0	38.7	16.1	0.0	0.0
Riding on Speedway tracks	ITA	0.0	2.3	1.2	4.7	75.6
	NZ	0.0	0.0	1.4	1.4	75.5
	NZY	0.0	0.0	3.2	0.0	80.6
Riding on Motocross tracks	ITA	2.3	9.3	18.6	8.1	45.3
	NZ	0.7	4.1	13.6	11.6	48.3
	NZY	3.2	3.2	32.3	6.5	38.7
Riding off-road or Enduro paths	ITA	0.0	1.2	11.6	3.5	67.4
	NZ	1.4	10.9	26.5	8.8	30.6
	NZY	3.2	6.5	32.3	16.1	25.8
Riding ATV/Quad	ITA	0.0	0.0	0.0	1.2	82.6
	NZ	0.0	2.0	1.4	4.1	70.7
	NZY	0.0	3.2	0.0	0.0	80.6
Riding Sidecar	ITA	0.0	0.0	0.0	0.0	83.7
	NZ	0.7	0.0	1.4	0.7	75.5
	NZY	0.0	0.0	0.0	0.0	83.9
Riding Supermotard	ITA	10.5	23.3	9.3	8.1	32.6
	NZ	0.0	0.7	1.4	9.5	66.7
	NZY	0.0	0.0	3.2	16.1	64.5
Riding Trial	ITA	2.3	0.0	2.3	0.0	79.1
	NZ	1.4	0.7	9.5	8.8	57.8
	NZY	3.2	0.0	9.7	3.2	67.7
Riding Flat-Track	ITA	4.7	4.7	8.1	10.5	55.8
	NZ	0.0	1.4	2.7	4.1	70.1
	NZY	0.0	0.0	6.5	3.2	74.2
Riding mini-bike or scooters	ITA	3.5	4.7	15.1	3.5	57.0
	NZ	0.7	1.4	3.4	7.5	65.3
	NZY	0.0	3.2	0.0	12.9	67.7
Riding SuperCross	ITA	0.0	1.2	3.5	2.3	76.7
	NZ	0.0	0.0	0.7	1.4	76.2
	NZY	0.0	0.0	3.2	0.0	80.6

Table 8.3. Different disciplines and motorcycles used by riders practicing riding.

Italian racers spent more time than NZ practicing riding, both "in season" and "off-season", with up to "more than four hours of active riding per week" for 38.4% of riders (Table 8.4).

Riding Training		7 or more hours of active riding per week	4 to 6 hours of active riding per week	2 to 3 hours of active riding per week	1 to 6 hours of active riding per month	Riding only during free practice sessions before competitions	No riding practice in-season
		How often riders practice riding (%)					
IN-SEASON	ITA	11.6	22.1	22.1	20.9	5.8	1.2
	NZ	2.0	5.4	19.7	36.7	13.6	0.7
	NZY	3.2	9.7	35.5	19.4	16.1	0.0
		7 or more hours of active riding per week	4 to 6 hours of active riding per week	2 to 3 hours of active riding per week	1 to 6 hours of active riding per month	Riding only during pre-season tests	No riding practice off-season
OFF-SEASON	ITA	10.5	27.9	20.9	17.4	3.5	3.5
	NZ	1.4	4.1	12.2	38.8	15.0	6.8
	NZY	3.2	3.2	16.1	38.7	16.1	6.5

Table 8.4. Frequency of practice riding the motorcycle.

Instructions or suggestions at the riding sessions were recorded to be mainly from a "family member" (12.2 – 24.4% range) or "my mechanic" (15.4%), but Italian racers reported to be also instructed by a "coach" (25.6%), and New Zealand from "other riders" (23.1%). Nearly a quarter of riders (17.7% to 26.7%) practicing riding skills training reported receiving no instruction ("nobody") during riding practice (Table 8.5).

Riding Training		Who gives instructions or suggestions to riders (%) Always	Very Often	Sometimes	Rarely	Never
Personal coach/trainer/tutor	ITA	7.0	5.8	0.0	3.5	67.5
	NZ	0.7	4.1	17.7	15.0	40.8
	NZY	3.2	6.5	16.1	9.7	48.4
Coach from team or club	ITA	10.5	2.3	2.3	0.0	68.7
	NZ	0.0	1.4	13.6	12.2	51.0
	NZY	0.0	3.2	12.9	12.9	54.8
Coach from the National Federation	ITA	0.0	0.0	1.2	0.0	82.6
	NZ	0.0	0.7	3.4	7.5	66.7
	NZY	0.0	0.0	3.2	9.7	71.0
My mechanic	ITA	10.5	4.7	7.0	2.3	59.4
	NZ	6.1	9.5	10.2	4.8	47.6
	NZY	12.9	12.9	12.9	6.5	38.7
Family member	ITA	19.8	4.7	5.8	2.3	51.2
	NZ	6.8	5.4	16.3	5.4	44.2
	NZY	19.4	12.9	25.8	3.2	22.6
Other Riders	ITA	7.0	4.7	7.0	2.3	62.8
	NZ	5.4	17.7	38.1	9.5	7.5
	NZY	9.7	35.5	22.6	9.7	6.5
Nobody	ITA	25.6	1.2	1.2	0.0	55.9
	NZ	7.5	10.2	11.6	4.8	44.2
	NZY	6.5	9.7	6.5	6.5	54.8

Table 8.5. Percentage of riders practicing riding with assisted instructions or suggestions.

Physical training

Physical training without the motorcycle was the most utilised form of training in preparation to competitions, and significantly more Italian riders declared to practice it than NZ riders: 98% versus

81%, respectively ($\chi^2_{(1)}$= 13.5; $p < 0.05$) (Table 8.6).

	Physical Training		How it is considered from riders (%)				
	Yes (%)	No (%)	Very Important	Important	Moderately Important	Of Little Importance	Unimportant
ITA	98	2	**77**	17	6	0	0
NZ	81	19	**49**	35	14	2	0
NZY	90	10	**65**	26	10	0	0

Table 8.6. Percentage of riders practicing physical training without the motorcycle and perceived importance.

The activities labelled as "strength training (weights) at the gym" (26.6 – 44.2%), "jogging/running" (29.9 – 40.7%) and "cycling/mountain biking" (23.8 – 40.7%) were the most utilised forms of physical training (Table 8.7).

Physical Training		How often riders (%) Always	Very Often	Sometimes	Rarely	Never
Jogging / Running	ITA	10.5	30.2	27.9	5.8	23.3
	NZ	10.2	19.7	21.1	16.3	13.6
	NZY	19.4	32.3	25.8	9.7	3.2
Cycling / Mountain biking	ITA	15.1	25.6	24.4	7.0	25.6
	NZ	10.9	12.9	27.9	10.9	18.4
	NZY	16.1	22.6	19.4	16.1	16.1
Stationary bicycle / Rower	ITA	5.8	8.1	9.3	8.1	66.2
	NZ	3.4	10.2	21.8	9.5	36.1
	NZY	3.2	22.6	19.4	9.7	35.5
Strength training (weights) at the gym	ITA	18.6	25.6	18.6	10.5	24.4
	NZ	8.2	18.4	20.4	11.6	22.4
	NZY	16.1	25.8	32.3	3.2	12.9
Soccer / Basketball / other team sport	ITA	3.5	5.8	10.5	10.5	67.5
	NZ	2.7	4.8	8.2	7.5	57.8
	NZY	9.7	9.7	19.4	3.2	48.4
Tennis / Racquetball / Baseball	ITA	0.0	1.2	8.1	2.3	86.0
	NZ	2.0	1.4	4.8	8.8	63.9
	NZY	3.2	0.0	3.2	9.7	74.2
Swimming	ITA	1.2	7.0	18.6	5.8	65.1
	NZ	1.4	5.4	13.6	13.6	46.9
	NZY	0.0	12.9	9.7	22.6	45.2
Martial arts / Combat sport	ITA	5.8	3.5	7.0	0.0	81.4
	NZ	2.7	1.4	4.1	2.7	70.1
	NZY	6.5	0.0	0.0	3.2	80.6
Fitness activity / Crossfit	ITA	7.0	25.6	19.8	8.1	37.2
	NZ	3.4	10.2	13.6	8.2	45.6
	NZY	0.0	16.1	12.9	9.7	51.6
Yoga	ITA	0.0	0.0	0.0	1.2	96.4
	NZ	0.7	2.7	5.4	4.8	67.3
	NZY	0.0	3.2	6.5	9.7	71.0
Other	ITA	0.0	1.2	3.5	1.2	91.8
	NZ	4.8	6.8	17.7	4.8	46.9
	NZY	3.2	3.2	9.7	3.2	71.0

Table 8.7. Percentage of different physical activities adopted by riders.

Similarly to riding practice, Italian riders reported to spend more time physically preparing than NZ riders (>80% versus <40% training "more than four hours per week", respectively), and while Italians increased their time dedicated to physical training during the "off-season", the New Zealand racers decreased it (Table 8.8).

		How often riders physically train (%)					
Physical Training		7 or more hours per week of physical training	4 to 6 hours per week of physical training	2 to 3 hours per week of physical training	1 to 6 hours per month of physical training		No physical training in-season
IN-SEASON	ITA	39.5	43.0	10.5	3.5		1.2
	NZ	17.0	22.4	26.5	13.6		1.4
	NZY	29.0	32.3	19.4	6.5		3.2
		7 or more hours per week of physical training	4 to 6 hours per week of physical training	2 to 3 hours per week of physical training	1 to 6 hours per month of physical training	Only pre-season physical conditioning	No physical training off-season
OFF-SEASON	ITA	46.5	37.2	10.5	2.3	1.2	0.0
	NZ	13.6	16.3	26.5	17.7	5.4	1.4
	NZY	19.4	25.8	25.8	12.9	3.2	3.2

Table 8.8. Frequency of practicing physical training.

While a "coach" or "instructor" was reported frequently guiding the physical training of Italian riders (79.1%), the majority of New Zealand riders (74.1%) stated they were training by themselves, with only 11.6% of racers being instructed by a certified trainer (Table 8.9).

Physical Training		Who guides riders' physical training (%) Always	Very Often	Sometimes	Rarely	Never
Certified S&C / Sport sciences coach	ITA	39.5	11.6	2.3	2.3	41.9
	NZ	2.0	2.7	7.5	4.1	64.6
	NZY	3.2	6.5	12.9	3.2	64.5
Coach from team or club	ITA	0.0	0.0	0.0	1.2	96.5
	NZ	0.0	0.0	1.4	2.0	77.6
	NZY	0.0	0.0	6.5	0.0	83.9
Coach from national federation	ITA	2.3	0.0	0.0	0.0	95.3
	NZ	0.0	0.0	0.0	0.7	80.3
	NZY	0.0	0.0	0.0	0.0	90.3
Physiotherapist	ITA	3.5	4.7	3.5	1.2	84.9
	NZ	0.0	2.0	15.0	6.8	57.1
	NZY	0.0	0.0	19.4	3.2	67.7
Gym / fitness / swimming instructor	ITA	17.4	8.1	1.2	1.2	69.8
	NZ	1.4	5.4	10.9	4.8	58.5
	NZY	0.0	19.4	16.1	0.0	54.8
Family member	ITA	9.3	1.2	1.2	0.0	86.0
	NZ	2.7	2.7	5.4	5.4	64.6
	NZY	3.2	6.5	6.5	6.5	67.7
Other riders	ITA	3.5	1.2	1.2	1.2	90.7
	NZ	0.7	0.0	2.0	8.2	70.1
	NZY	0.0	0.0	3.2	9.7	77.4
Myself	ITA	26.7	3.5	1.2	1.2	65.2
	NZ	61.9	12.2	3.4	0.0	3.4
	NZY	77.4	9.7	3.2	0.0	0.0

Table 8.9. Percentage of riders guided in physical training.

Specificity of training

Riding-skills training programs were specifically designed or methodologically organised more often among NZ riders compared to Italians (43.5% versus 34.9% respectively); conversely, the specificity of the design of the physical training sessions was higher among the Italians (73.3% versus 27.9%) (Table 8.10).

Specificity of Training		How often riders train/practice with a specific program (%)				
		Always	Very Often	Sometimes	Rarely	Never
RIDING	ITA	15.1	19.8	20.9	10.5	17.4
	NZ	18.4	25.2	27.2	6.8	0.7
	NZY	19.4	29.0	25.8	9.7	0.0
PHYSICAL	ITA	39.5	33.7	15.1	4.7	4.7
	NZ	7.5	20.4	25.2	17.7	10.2
	NZY	9.7	25.8	25.8	19.4	9.7

Table 8.10. Percentage of riders practicing with specific programs (i.e. technical riding with dedicated sessions or physical training designed for specific demands of motorcycle racing).

Mental training

Riders in New Zealand (59%) practiced mental training more so than their Italian counterparts (43%) ($\chi^2_{(1)}$= 5.69; $p < 0.05$) (Table 8.11).

	Mental Training		How it is considered from riders (%)				
	Yes (%)	No (%)	Very Important	Important	Moderately Important	Of Little Importance	Unimportant
ITA	43	57	**41**	29	21	7	2
NZ	59	41	**37**	30	24	7	1
NZY	65	35	**48**	26	16	10	0

Table 8.11. Percentage of riders practicing mental training and perceived importance.

Use of “imagery/visualization”, “focusing attention/concentration” and “goal setting” were the most frequently used techniques in both populations (range 22.1 – 44.9%) (Table 8.12), whereas the use of music to modulate rider's level of arousal before the races was implemented more so by the Italians (29.1% versus 14.3%; $\chi^2_{(4)} = 35.2$; $p < 0.05$) (Table 8.13).

Mental Training		How often riders (%) Always	Very Often	Sometimes	Rarely	Never
Relaxation techniques	ITA	8.1	9.3	8.1	1.2	16.3
	NZ	5.4	14.3	22.4	10.2	6.8
	NZY	6.5	6.5	22.6	19.4	9.7
Goal setting	ITA	12.8	9.3	4.7	3.5	12.8
	NZ	15.6	24.5	11.6	4.8	2.7
	NZY	25.8	25.8	3.2	9.7	0.0
Focusing attention / Concentration	ITA	18.6	14.0	5.8	1.2	3.5
	NZ	17.0	18.4	19.7	1.4	2.7
	NZY	22.6	25.8	16.1	0.0	0.0
Emotional control	ITA	2.3	5.8	5.8	2.3	26.7
	NZ	7.5	17.0	15.6	6.8	12.2
	NZY	3.2	16.1	22.6	6.5	16.1
Imagery / Visualization	ITA	15.1	8.1	5.8	5.8	8.2
	NZ	20.4	24.5	11.6	2.0	0.7
	NZY	25.8	25.8	6.5	6.5	0.0
Self-talk	ITA	9.3	8.1	1.2	3.5	20.9
	NZ	12.9	15.0	15.0	11.6	4.8
	NZY	19.4	16.1	16.1	9.7	3.2
Other	ITA	1.2	0.0	0.0	0.0	41.9
	NZ	6.1	8.2	11.6	5.4	27.9
	NZY	12.9	6.5	12.9	3.2	29.0

Table 8.12. Percentage of different techniques of mental training used by riders.

		How often riders (%)				
		Always	Very Often	Sometimes	Rarely	Never
Listening music before competitions	ITA	20.9	8.1	15.1	5.8	50.0
	NZ	2.7	11.6	17.7	28.6	39.5
	NZY	3.2	25.8	22.6	29.0	19.4

Table 8.13. Percentage of riders using music to modulate their arousal level before competitions.

During the "in-season" period, the majority of the riders declared to be practicing mental training "only before competitions" or "from one to six hours per month" (range 12.8 – 28.6%), while during the "off-season" riders tended to reduce or stop such practice (Table 8.14).

		How often riders practice mental training (%)					
Mental Training		7 or more hours per week of mental training	4 to 6 hours per week of mental training	2 to 3 hours per week of mental training	1 to 6 hours per month of mental training	Only before competitions	No mental training in-season
IN-SEASON	ITA	1.2	2.3	7.0	12.8	18.6	1.2
	NZ	6.8	2.0	4.1	17.0	28.6	0.7
	NZY	9.7	3.2	3.2	25.8	19.4	3.2
		7 or more hours per week of mental training	4 to 6 hours per week of mental training	2 to 3 hours per week of mental training	1 to 6 hours per month of mental training	Only pre-season mental training sessions	No mental training off-season
OFF-SEASON	ITA	0.0	3.5	3.5	10.5	4.7	20.9
	NZ	4.8	0.7	5.4	17.0	15.0	16.3
	NZY	6.5	0.0	3.2	29.0	9.7	16.1

Table 8.14. Frequency of practicing mental training.

Only 14% of Italians used a "certified psychologist/mental coach" to guide their mental training, otherwise, the mental practice was self-guided in both populations (range 22.1 – 55.8%) (Table 8.15).

Mental Training		Who guides riders' mental training (%) Always	Very Often	Sometimes	Rarely	Never
Certified psychologist / Mental coach	ITA	14.0	0.0	2.3	2.3	24.4
	NZ	0.0	1.4	3.4	2.0	52.4
	NZY	0.0	3.2	0.0	3.2	58.1
Personal coach / trainer / tutor	ITA	3.5	1.2	0.0	0.0	38.4
	NZ	0.0	1.4	1.4	3.4	53.1
	NZY	0.0	0.0	3.2	3.2	58.1
Coach or trainer from the motorcycle club or team	ITA	0.0	0.0	0.0	0.0	43.0
	NZ	0.0	0.0	1.4	2.7	55.1
	NZY	0.0	0.0	0.0	3.2	61.3
Coach or trainer from the national federation	ITA	0.0	0.0	0.0	0.0	43.0
	NZ	0.0	0.0	0.0	1.4	57.8
	NZY	0.0	0.0	0.0	3.2	61.3
Physiotherapist	ITA	0.0	0.0	0.0	0.0	43.0
	NZ	0.0	0.0	4.1	1.4	53.7
	NZY	0.0	0.0	6.5	0.0	58.1
Instructor from gym or fitness or swimming pool	ITA	2.3	1.2	0.0	0.0	39.5
	NZ	0.0	2.7	1.4	0.7	54.4
	NZY	0.0	6.5	0.0	0.0	58.1
Family member	ITA	1.2	2.3	1.2	0.0	38.4
	NZ	1.4	3.4	6.1	2.7	45.6
	NZY	0.0	3.2	9.7	0.0	51.6
Other rider	ITA	0.0	0.0	0.0	0.0	43.0
	NZ	0.7	1.4	6.1	6.1	44.9
	NZY	0.0	0.0	0.0	9.7	54.8
Myself	ITA	17.4	4.7	0.0	0.0	21.0
	NZ	51.7	4.1	0.7	0.7	2.0
	NZY	61.3	3.2	0.0	0.0	0.0

Table 8.15. Percentage of riders assisted in mental training.

Injury prevention

Remarkably, the injury prevention practice was considered the least important type of training (from 22.4% to 24.4% of "little importance" or "unimportant") and 71 – 78% of riders declared to "never" practice crash-skills exercises (Table 8.16).

Injury Prevention		How often riders (%) Always	Very Often	Sometimes	Rarely	Never
Perform body warm-up before riding	ITA	**57**	12	13	3	15
	NZ	20	**27**	22	17	14
	NZY	16	26	**32**	19	6
Use earplugs in competition	ITA	29	1	2	1	**66**
	NZ	**35**	9	10	12	34
	NZY	**42**	10	6	13	29
Suffer forearm compartmental syndrome	ITA	2	12	15	8	**63**
	NZ	0	5	24	32	**39**
	NZY	0	13	29	**32**	26
Perform muscular stretching at training	ITA	**58**	14	20	2	6
	NZ	**26**	24	22	16	12
	NZY	29	**32**	16	13	10
Practice crash-skills training	ITA	2	3	6	10	**78**
	NZ	1	2	4	21	**71**
	NZY	0	0	6	19	**74**

Injury Prevention Training	How it is considered from riders (%) Very Important	Important	Moderately Important	Of Little Importance	Unimportant
ITA	**31**	24	20	13	12
NZ	15	30	**33**	20	3
NZY	19	**29**	23	26	3

Table 8.16. Percentage of riders practicing injury prevention training and perceived importance.

Discussion

This study aimed at describing how New Zealand and Italian licensed motorcycle circuit racing riders prepare to compete, and the main findings highlight that: 1) training methods and approaches are not uniform among riders from the two different continents; 2) there is a tendency to lack professional guidance in training programs for these populations of athletes; and, 3) practicing active injury prevention appears unimportant to riders.

As typical in sports, athletes and coaches identify technical, physical and tactical components of performance, consequently, preparation programs usually aim at improving such areas. From the findings of this study, to be successful in competitions, motorcycle circuit racers consider riding skills more important than physical and mental aspects, respectively. However, there are more riders that include physical training in their preparation programs, and surprisingly about one out of five riders (16-22%) do not practice riding motorcycles. Replicating competition-conditions with the purpose of practicing riding skills is often problematic (i.e. motorcycles are usually property of racing teams and the costs of circuits, logistics and technicians are substantial), therefore riders may use other forms of motorcycling to train. Riding on asphalt circuits recorded the highest occurrences in both groups, however Italians reported to also use Supermotard and less frequently Motocross, Flat-track and Mini-bikes, while NZ racers preferred to practice with off-road disciplines such as Enduro.

Physical training was included in the preparation of Italian riders significantly more than NZ riders, but the outcome was reversed for mental training, which was significantly more popular among racers in NZ. Interestingly, with the exception of mental training practices, the subgroup of NZ riders below the age of 30 recorded similar results to the Italian population of racers, perhaps indicating that some European standards are considered important in younger generation racers, in order to achieve higher level of success. Physical activities aiming at cardiovascular conditioning were adopted from all participants, however a higher use of muscular strength training was found in the Italians. Also, Italian riders reported higher volume of time for training their riding skills and their body during the in-season period, and while NZ riders decreased their training in the transition time between competitive seasons, the Italians tended to slightly increase it. The reduced use of physical preparation in NZ might perhaps be explained by the fact that national competitions have shorter duration and are held in lower-standard circuits compared to racing in Italy, while the frequency of practicing riding might be influenced by the presence/accessibility of facilities and the climatic conditions.

In both populations, the most frequently used mental techniques were imagery/visualization, focusing attention/concentration and goal setting, however the majority of riders declared to be practicing mental training only before competitions during the in-season period, and having no mental training during the off-season. Interestingly, despite NZ riders practicing mental training significantly more than Italians, they made significantly less use of music to modulate their level of arousal before the races.

Although the complexity of the performance and the financial investments required in this sport, the findings of this survey revealed that often motorcycle riders are not assisted by professionals in guiding their training programs. It is expected that the practice and development of riding skills should be guided from certified experts and/or licensed national Federation coaches, however only a small portion of Italian riders declared to be aided by a coach, otherwise instructions or suggestion during riding sessions were provided from a family member, other riders, the rider's mechanic, or riders received no instruction. Self-guidance was even more popular for the physical and mental training sessions, especially among NZ riders. Indeed, the majority of NZ racers declared to be selfinstructed for their physical training, while more than half of Italian riders responded to be always guided by a certified strength and conditioning coach or instructor from the gym. In line with previous research (Martin et al., 2015; Rodriguez-Perez et al., 2013), the low specificity found in the design of the training programs (Table 10), could be explained by these coach-less approaches. Such findings were particularly surprising for the mental training, where specific instructions, live feedback and meticulous guidance are expected to successfully complete activities such as imagery, goal setting or emotional control. Nevertheless, almost all NZ riders indicated that they performed mental training by themselves and only a small percentage of Italians were assisted by a psychologist or mental coach.

The risks of injury in motorcycle circuit racing are well-established (Bedolla et al., 2016; Hinds et al., 2007; Zasa et al., 2016), however riders seemed to underrate the preparation practices aimed at active injury prevention. Although a portion of racers considered training for injury prevention important to be successful, still this kind of training was rated the lowest in importance. In a sport where at the professional level, 12 to 14% of riders starting a dry race suffer a crash (D'Artibale, Rohan et al., 2018), it is perplexing that more than 70% of riders never practice crash-skills techniques.

Moreover, the prevention of physical overloads seems to be underestimated. For example, the forearm compartmental syndrome is a pathology often related to motorcycle racers (Barrera-Ochoa et al., 2016; D'Artibale et al., 2018b), however muscular stretching was not a consistent routine for this population of athletes, and the lack of research investigating alternatives to surgical decompression does not help provide evidence/knowledge to guide good practices in this area. Similarly, a minority of riders used earplugs during competitions, despite the prolonged exposure to a high-decibel environment that likely represents a risk for hearing loss (McCombe et al., 1994).

Practical Applications

This study described current approaches of circuit racing motorcycle riders in preparation for competitions, hence, national Federations, coaches, managers of associations, teams or racing organizations could consider these findings while discussing strategic plans or formulating discipline-specific guidelines aiming at advancing the competitiveness of their affiliated racers. Appendix D to this thesis offers an example of potential solutions and applications elaborated for the sponsor of this doctoral research in relation to the results of NZ riders.

Moreover, the exposure to risks and injuries of motorcycle racing has been well documented, therefore insurance companies and other institutions such as motorcycling Federations or official manufacturers racing teams, might be interested in preserving the career of riders, and may benefit from the implementation of the information here provided. Success-oriented investors in motorcycle racing may benefit from applying such monitoring instruments and implementing strategies and activities (i.e. specialised high performance training, injury prevention courses, etc.) that aim at the development of these athletes.

Conclusion

This study investigated preparation practices adopted from two populations of motorcycle racers from different continents. New Zealand and Italian riders have slightly different ways to approach training, however, in both countries professional guidance to training appears lacking. Not all riders practice riding-skills, while physical training is widely adopted, in a variety of forms and frequencies. Mental training and injury prevention practices are the less considered areas of preparation and the majority of riders never practice crash-skills training. Due to the technical, physical and mental demands of professional motorcycle circuit racing, riders aiming at developing their careers are suggested to get assistance with specific and tailored training programs. Potential benefits of multidisciplinary, specific, evidence-based training could optimise rider's performance and their teams' investments. Prevention training (i.e. crash-skills techniques) may generate short and long term benefits in a rider's career and further research on this sensitive topic could validate methodologies supporting the development of athletes in this sport. National Federations and racing organizations could consider formulating discipline-specific guidelines for preparation practices to advance the competitiveness of their affiliated racers.

Chapter 9 – Summary, practical applications and future research directions.

Summary

Circuit racing motorcycling is a team sport with a variable number of members, in which the final result is determined from an individual performance (i.e. rider) combined with the performance of the final product of the team (i.e. the motorcycle) along with the performance of tyres and the interaction with the environment. It is a situational sport where each participant competes against multiple opponents.

Compared to the technological developments of the motorcycles and the investments dedicated to the engineering and mechanical components of performance, the scientific research studying the human factors involved in this sport is minimal, therefore methodical analysis of rider's performance and relative strategies aiming at racer's holistic development are mostly unpublished.

This thesis aimed at advancing knowledge and professional practice regarding the human factors in the field of motorcycle circuit racing. The ultimate goal of this doctoral research was to provide a scientific base for refining rider-training programs specifically designed to support and improve riders' performance. The application of scientifically-based findings into training practice contributes to the development of athletes competing in motorcycle circuit racing events. Indeed, the findings of this thesis may offer to riders, racing teams, motorcycling associations/federations and motorcycle manufacturers, a unique resource to improve their approach to racing, which is expected to lead to performance and safety enhancement during competitions.

A multidisciplinary approach was used to answer the research question “which physical and cognitive factors are important in optimising the rider's performance in motorcycle circuit racing competitions?” Therefore, profiling the physiological requirements, the mechanical stresses, and the psychological strategies with the aggregate purpose to improve the understanding of the rider as an

athlete has been at the core of this project. It was thought necessary to take such a multidisciplinary approach, as performance is an integration of many components and to understand the physical requirements, for example, without understanding the influence of other factors, would seem less than comprehensive. Saying that we acknowledge that each of the components (i.e. physical, physiological, environmental and psychological) studied in this thesis could be a PhD in and of themselves, and there could be a criticism that the PhD lacks depth given the breadth of understanding sought. However, this was a considered decision very early in the PhD journey as we did not want a siloed understanding of a singular aspect of the human side of circuit racing motorcycling, rather an integrated understanding of the demands of this sport at the highest level. As such, we feel we have achieved this mostly, ultimately advancing the knowledge base in this sport, which in turn enables practitioners to better prepare the rider for the demands of racing. A summary of the main findings from the thesis is now provided.

Chapter 2

From the review of the scientific literature, it is evident that motorcycle competitions expose riders to potential injuries, indeed at the top level an incidence rate of 9.7 crashes per 100 riding hours was recorded, with 11.5% of crashes causing significant injuries to riders (i.e. bone fractures, concussions) (Bedolla et al., 2016). Skeletal fractures were the most common consequences of crashes and the limbs seemed to be the most vulnerable site of injury - upper limbs, shoulder, wrist and hand in primis - since they were identified to be used to break falls and to protect more important parts, such as the head (Bedolla et al., 2016; Chapman et al., 1991; Costa et al., 1983; Hackney et al., 1993; Horner at al., 1986; Tomida et al., 2005; Varley et al., 1993; Zasa et al., 2016). Serious injuries (i.e. brain, spinal cord, internal chest and abdomen) at the top level of this sport were rare, but an injury rate ranging from 3.8 per 1000 race kilometres in the MotoGP class to 16.9 injuries per 1000 race kilometres in the Moto3 class was reported (Zasa et al., 2016). However, it's important to also consider that riders were exposed to pathologies related to the environmental and mechanical stress of racing, i.e. noise-induced hearing loss and chronic exertional compartment syndrome of the forearms (Barrera-Ochoa et al., 2016; Garcia-Mata, 2013; Gondolini et al., 2017; Goubier et al., 2003; McCombe et al., 1994; McCombe et al., 1995).

From a physiological load perspective, direct measurements of heart rate during official competitions indicated that competitive riding resulted in a high cardiovascular load on riders, i.e. HRmax above 90% for the majority of the race (D'Artibale et al., 2007; D'Artibale et al., 2008; Filaire et al., 2007). The substantial metabolic load of motorcycle racing was documented from the post-race concentrations of blood lactate i.e. from 4.5 to 6 mmol/l (D'Artibale et al., 2007; D'Artibale et al., 2008; Filaire et al., 2007), the direct gas analysis during riding i.e. seven times the basal value (D'Artibale et al., 2013), and the cortisol concentration measured after the race i.e. 57 nmol/l (Filaire et al., 2007). Moreover, motorcycle racing events held at high ambient temperatures and elevated environmental humidity represented a thermal stress for riders (Brearley et al., 2014). Although the body mass and size of riders was considered influential to racing performance (Sánchez-Muñoz et al., 2011), young riders competing internationally reported to have a poor approach to preparation for competitions, lacking specificity of training and professional programming, with only about a third of them being supported from a coach (Martin et al., 2015; Rodríguez-Pérez et al., 2013).

The psychological demands of motorcycle racing are embedded within the specific characteristics of the sport, and control of pre-competition anxiety, self-confidence, use of focusing and imagery techniques were considered fundamental in riders' career (Dosil et al., 2006). Moreover, the personality construct of hardiness, which is a personality characteristic anticipated to explain the differences in mood states among individuals subjected to stress, was found to be significantly higher in professional riders than in club racers (Thomas et al., 2013).

Chapter 3

A limitation identified from the literature review, was the lack of detail describing the parameters that define top performance in circuit racing motorcycling, which is important to establish a benchmark understanding of the characteristics of professional level racers. Chapter 3 therefore aimed to determine performance characteristics, identify potential changes through time, and quantify potential interactions between race data from 278 dry races at the top class of the FIM road racing Grand Prix world championship. The main findings indicated that for the top ten riders a competition lasted on average 44 minutes 15 seconds ± 1 minute 59 seconds, racing at a mean speed ranging from 157 ± 8 to 163 ± 7 km/h. Interestingly, from 1997 to 2016, the speed of dry racing of the top class increased by 4%, and the race winners started from pole position 46.8% of the time, while only 17.6% of race winners succeeded starting from anywhere after the first row at the starting grid. At the top level of racing, independent from environmental factors and speed of competition, 12-14% of starters experienced a crash during a race, therefore a crash happened on average every 44.6 km of racing. In those two decades, an estimated fatality rate of 0.028% was calculated.

Chapter 4

From Chapter 2 it also emerged that no researchers had described the mechanical load riders experienced due to fast riding. Hence, Chapter 4 aimed at profiling the physical load experienced by top level riders by analysing race results alongside kinematic reports from three seasons of the MotoGP championship. The main findings were that professional riders were required to navigate 15 ± 2 corners and 7 ± 1 braking actions per lap, therefore during actual competitions, they braked 175 ± 42 times and leaned into the corner 372 ± 48 times per race. A braking action lasting 4.2 ±

0.6 seconds in duration happened on average every 11.6 ± 4.1 seconds of their racing, and over 40% of the braking actions were initiated at a speed higher than 260 km/h; therefore riders experienced a mean negative acceleration ranging from 16.5 m/s^2 to 2.7 m/s^2, and 25% of these inertial stresses were greater than 10 m/s^2. Professional riders in this cohort were found to be relatively light in body mass (from 63.2 ± 5.3 to 65 ± 6.7 kg) with a mean stature slightly above 170 cm and a mean age of 27 years.

Chapter 5

As previously highlighted, the forces on the human body associated with motorcycle racing are currently unpublished, and Chapter 5 is an expansion of the previous chapter focusing on the mechanical stresses experienced by riders. This study therefore aimed at quantifying the negative and positive accelerations that racers experienced during real competitions via direct measurements of different classes of racing. Riders in an entry-level class championship (EJC) experienced 87 ± 11 brakes per race, while national (NSS) and world (WSS) SuperSport 600 class championships were found to have on average 144 ± 14 and 171 ± 28 brakes per race, respectively. Riders in WSS class experienced on average 3.8 seconds of braking every 7.5 seconds of racing and 12% of their braking actions were initiated at a speed higher than 240 km/h. For each braking action, the calculated inertial mean force acting on the rider centre of gravity was from 476 to 513 N on average, and peak forces doubling these values. Moreover, the mean inertial forces generated while accelerating to exit the corners were from 300 to 384 N on average, with the WSS class recording 33% larger accelerations compared to the entry category EJC.

Chapter 6

The literature review offered a limited overview of the physiological responses to motorcycle racing and identified the thermal stress as a potential performance limitation for riders. Thus, Chapter 6 focused on quantifying the impact of heat on the rider's body and exploring potential strategies to mitigate such physiological stress during actual competitions. Over seven riding sessions, held with environmental temperatures of 31 ± 2.2°C, the mean value of rider's maximal gastrointestinal temperature was 39 ± 0.5°C, with a maximal value of 40.1°C recorded during a podium-finisher race. During riding, the riders' gastrointestinal temperature increased at 0.05 ± 0.01°C/min, the dorsal region and the upper arm recorded the highest skin temperatures under the leather suit, and the riders lost on average 1.63 ± 0.5 kg of fluids (2.2 ± 0.8% of the riders' body mass). Although the pre-cooling strategy of ice-slurry ingestion and neck cooling received positive feedback from riders, a faster increase of gastrointestinal temperature was observed and no physiological measurements reflected such perceived benefits, therefore more data was considered necessary to clarify responses of interventions aiming at mitigating the thermal stress experienced during racing.

Chapter 7

Another gap discovered from the literature review, was the paucity of research dedicated to understanding the psychological aspects of racing or the mental skills required to succeed in this sport. Consequently, Chapter 7 was dedicated to understanding the psychological skills and strategies used by riders in competition and practice settings, through the use of a validated self-report instrument (i.e. Test of Performance Strategies - TOPS2 by Hardy, Roberts, Thomas & Murphy 2010). The analysis of a limited population of international riders revealed that the most frequently used skill was automaticity, both in practice (4.05 ± 0.45) and competition (4.18 ± 0.60), while the use of relaxation techniques in competition ($r = 0.80$; CI: 0.34 – 0.95) and at practice ($r = 0.74$; CI: 0.21 – 0.93) resulted in a large correlation with the number of races that a rider had accumulated during his/her career. Compared to other sports and Olympic medallists, motorcycle racers scored lower emotional control both at practice and in competition, along with higher negative thinking and automaticity. Surprisingly, riders with more wins recorded lower scores in the majority of psychological subscales and more research with larger sample sizes are required to clarify the relationships between the use of performance strategies and success or experience in motorcycle racing.

Chapter 8

Although this sport requires a complex combination of physical, technical and mental skills, the literature review detailed two studies reporting riders having a poor approach to preparation to competitions. To define the current practice of motorcycle racers from New Zealand and Italy, Chapter 8 aimed at exploring their approaches to preparation, by investigating the activities that riders adopt to meet the demands of their sport. Results from 233 interviewed riders revealed that training methods and approaches were not uniform among racers from the two different continents, with the New Zealand riders practicing significantly less physical training and more mental training than Italians. A tendency to lack professional guidance in training programs and specificity in their design emerged from both populations, with only 6.8% and 3.4% of NZ riders declaring to be always assisted in physical and mental training sessions, respectively. Surprisingly, the injury prevention practice was considered the less important practice and 71 – 78% of riders declared to "never" practice crash-skills training.

The findings from this collection of chapters led to the following practical applications.

Practical Applications

The following section offers a unique resource to riders, coaches, managers of racing teams, representatives of motorcycling associations/federations and any individual interested in improving the human component of motorcycle racing. Based on the learnings acquired from this thesis, the practical applications are organised to focus on specific areas of performance and injury prevention.

Riding

To improve fast-riding ability, riders are recommended to practice riding skills and design their sessions with specific and methodologically organised technical elements such as throttle control, steering (i.e. bike yawing), gearing, body postures, braking phase, corner entry, lines and apex selection, corner exits, etc. Riding can be practiced in many forms and with a variety of motorcycles, however it is highly recommended to focus on activities in which skill-transfer would be beneficial for circuit racing.

Training on motorcycles should stimulate the rider's sensitivity, exercise the responses to setup adjustments, teach riders to maximise their goal setting strategies, and build confidence in high-speed manoeuvres. The advantages would be enhanced if practiced together with other riders. Moreover, practicing high-speed riding exposes riders to the specific physical stresses and stimulations, therefore specific adaptations are expected, making the riders "bike-fit", which pertains to the physical, physiological, environmental and cognitive demands of the sport.

Cardiovascular fitness

The duration of the races (up to 44 minutes) and the volume of riding sessions during the multi-day competition events, require riders to possess adequate cardiorespiratory fitness. Riders are recommended to engage in activities that increase their ability to: 1) deliver aerobic power for the demands of prolonged high-speed riding; 2) delay fatigue appearing after multiple consecutive fast laps; and, 3) maximise their recovery/energy-restoring ability during the time in between riding sessions.

Sessions of cyclic activities (i.e. rowing, cycling, running), lasting at least as the longest riding session faced during the race-weekend (i.e. 30-60 minutes), performed at moderate to vigorous intensities, may allow riders to finely control the cardiovascular response in relation to intensity and duration of effort, in order to learn how to manage energy-levels throughout the riding sessions. Due to the involvement of upper body musculature while riding, whole-body workout (i.e. cross-trainer/elliptical machine, rower) or an alternation of upper and lower body exercise (i.e. arm-bike machine and cycling) should be considered. Due to the necessity of minimising muscular mass gain to avoid the increase of body weight, uphill cycling should be carefully considered, due to the hypertrophic adaptations it may have on leg muscle mass. Circuit training exercises (i.e. high intensity interval training with calisthenics or free body functional-training exercises) are a recommended solution to create the stimuli necessary for improving muscular strength and aerobic fitness simultaneously. Overall, we recommend riders increasing their anaerobic threshold to maximise the contribution and efficiency of aerobic metabolism during racing.

Muscular strength and endurance

Competitive riding requires specific muscular demands due to the frequency, volume, duration and intensity of actions performed during competitions. To be prepared to counteract the inertial forces generated by the longitudinal accelerations (i.e. braking and corner-exits), to maintain strength and accuracy of handgrip and wrist motion (i.e. lever pulling and throttle twisting), and to finely control the body positions assumed in cornering and on the straight (i.e. tank hang-off, aerodynamic penetrative posture), riders are recommended to prepare their musculoskeletal system with exercises that replicate the efforts, volumes, and biomechanics of riding.

For example, considering that riders are exposed to up to 175 braking actions and 372 corners per race, are subjected to peak inertial forces during braking above 1000 N, and those forces increase with more powerful motorcycles, it is suggested to exercise muscular strength and endurance, in eccentric, isometric and concentric modalities, for the symmetrical and asymmetrical pushing and pulling patterns of upper limbs movements. In addition, riders are recommended to possess core stability, balance and muscular endurance in the lower limbs, which are also recruited concentrically, isometrically and eccentrically, to efficiently control the several lateral shifts during cornering and the unilateral or bilateral pushes on the foot-pegs and fuel tank during cornering and accelerations. For both the upper and lower body training, free-body exercises with closed kinetic chain movements (i.e. planks, squats, etc.) are considered beneficial for riders since they require fine postural control, allow to work on body centre of mass displacement, and slow alternated movements stimulate the awareness of load transfer, which are key elements of motorcycle riding.

Moreover, riders must pay particular attention in maintaining musculoskeletal fitness and health in their forearms, due to the potential risks of overload as a consequence of the mechanical stresses experienced by this musculature, as highlighted in the thesis. Therefore, it is suggested that the rider engages in exercises focusing on wrist flexion and extension, as well as grasping holds and finger flexions, executed with high range of motion, aiming at progressively establishing muscular endurance along with elasticity of all the tissues in this anatomical region. Since the chronic exertional compartment syndrome is a reversible form of abnormally increased intramuscular pressure (Barrera-Ochoa et al., 2016), the aim of forearm training should be strengthening the tissues involved in muscular contractions ensuring that they stay flexible and tolerant to their expansion.

Body composition

In motorsports, the importance of the power-to-weight ratio is well established, therefore the final mass of the rider-motorcycle binomial must be considered as a factor influencing the final performance. Hence, although riders are recommended to possess the necessary muscular strength to control the forces associated with racing, they are also suggested to minimise the body weight gain associated with the increase of muscle mass. Therefore, riders should carefully monitor their anthropometric measurements and be assisted with tailored nutritional and training plans aiming at optimising their body composition.

Flexibility

As mentioned earlier, to decrease the muscular tension and avoid overload in the forearms, riders are suggested to possess an efficient level of flexibility in the tissues involved with wrist and hand movements. Therefore, riders are strongly recommended to integrate in their routine exercises of stretching for the muscles and tissues involved in finger flexion and wrist flexion/extension.

In addition, due to the amounts of cornering actions and the postural position held when leaning with the motorcycle, riders are suggested to exercise the range of motion of their shoulders, in order to be able to execute the wide range of movements pre-requisite to performing cornering manoeuvres. Lastly, riders are recommended to possess a sufficient flexibility at the hips and spine, in order to efficiently hold the aerodynamic penetrative position on board of their motorcycle, and the posture when a preventative tumbling technique is utilised during a crash.

Heat tolerance

When competitions are scheduled in hot environments (i.e. above 25ºC), riders are recommended to follow preparation plans allowing them to minimise the hyperthermia-induced impairments associated with heat stress. Therefore, riders are suggested to: 1) become acclimatized and develop heat tolerance; and, 2) have strategies in place to minimise heat accumulation, cooling their overall temperature before and if possible during performance.

To improve heat tolerance during competitions, riders can plan to travel in advance to the hot location where the competition is held, can practice riding and training physically in the heat, and can periodically schedule saunas or sessions in hot chambers to develop individual adaptations reducing the impact of heat. In addition, riders are strongly encouraged to have systematic hydration plans before and during the events, along with adopting strategies of pre-cooling or cooling aiming at decreasing or retarding the internal accumulation of heat. Ice-slurry ingestion, neck cooling, cold-water immersion and undergarment cooling systems are potential solutions.

Injury prevention

Considering that at the top level of motorcycle circuit racing, 12% to 14% of starters have been recorded as being involved in a crash during a dry race, we recommend that athletes competing in this sport should be prepared to cope with such events. To minimise chances of injuries, riders are recommended to learn tumbling and stunting techniques, aiming at managing the impacts following a crash. Obviously, the dynamics of a crash could be unpredictable, however crash-skills techniques can support riders in the active prevention of injuries in those typical falls, where there is time and space for a rider to apply them. In addition, racers competing in categories where the summation of wind-noise and engine-sound can represent a threat for hearing damage, it is suggested that riders use noise-reduction devices while performing.

Mental toughness and emotional control

According to the frequency of crashes, the exposure to potential injury, and the personality construct of professional racers highlighted in this thesis, riders are recommended to consider developing mental toughness to cope with the peculiarities of this sport. The psychological stresses connected with the costs and risks of racing, the resilience to adversities necessary to develop a rider's career, and the complexity of circumstances that can be experienced during race-weekends suggest that riders aiming at high performances, should get assistance from professionals in adopting strategies to cope with emotions and anxiety experienced in the short and long term.

Racers aiming at improving their performance are recommended to engage in programs including the development of psychological skills such as emotional control, goal setting, relaxation and imagery techniques, and positive thinking.

Tactical behaviour

Considering the influence on the final result of both the starting grid position and the rider's race-pace (i.e. single fast-lap versus multiple consecutive laps, with relative selection of tyre type), racers together with their team are required to strategically plan their Free Practices, Qualifying and Warm-Up sessions, in order to "build" with efficiency the final outcome at the race. Adding to the complexity of this equation is the influence that weather or environmental conditions may have on the final performance (i.e. 16% of international competitions were raced in wet conditions). Therefore, to maximise the benefits arising from the multiple riding sessions scheduled in preparation to racing, and to manage the competition event with efficiency, riders aiming at the top level of the sport are recommended to develop tactical skills and receive assistance from experts to support the creation of strategic plans that involve specific goal setting and targeted behaviours to optimise the riders and team's success.

Holistic approach to performance

Considering the multifactorial nature of the sport (i.e. competition result = motorcycle performance + human performance + tyres performance + interaction with environmental/situational factors), and the relative costs and risks included in a racer's career, it appears important that riders develop awareness and responsibility towards factors that contribute to competition outcomes. In the world of motorcycle circuit racing, it's well known that it's not the fittest rider nor the most powerful engine that win the races, but the “best package”. Therefore, in parallel to the work of the engineers developing the motorcycle, it is envisaged that highly specialised human performance experts assist riders with “Individual Performance Plans” (IPP) aiming at the holistic development of this athlete. Such IPPs offer performance preparation, including integrated programs specifically designed to improve: physical and physiological abilities, riding skills, injury prevention practices, cognitive and psychological processes, and, environmental and tactical solutions. While individual professionals (i.e. sport psychologist, dietician, riding coach, etc.) provide contribution to the programs, a motorcycling performance specialist would assist the riders in their trainings according to categories of competitions and phases of career, and the practical applications arising from the findings of this thesis form much of the criteria guiding the rider's IPP.

Future Research

Due to the limited published research currently available on the human factors of motorcycle circuit racing, there are several focus areas that would benefit from additional research to improve the performance and safety of riders.

Since circuit racing motorcycling is a high-risk sport, enhancing its safety could be considered a priority in the evolution of the sport. Material and technology advancements have evidently improved the safety of riders, however no publications corroborating the efficiency of current protective equipment are yet available, such as in-field data analysing the benefits of the leather-suits equipped with airbag system. Similarly, circuit standards are thought to be at the highest level of safety, but unfortunately there is no published evidence on the efficiency of the different environmental safety strategies adopted, such as air-fences, gravel traps, or asphalt run-off areas.

In relation to these topics, and to the dynamics of crashes, future research should focus on the potential solutions to reduce injuries to riders, starting from investigating the causes of the fatalities and serious injuries occurring at any level of the sport. Parallel to this, future experimental studies should investigate the relevance that preventative behaviours such as specific muscular strengthening/stretching or crash-skills training could have on reducing muscular overload syndromes and lowering the risk of skeletal injury in riders in the event of a fall/crash.

In regards to performance evolution, future research should have the ambitious goal of identifying the factors determining the success of a rider, in terms of technical, physical and mental aspects, in relation to the individual characteristics and category of competition. For example, biomechanical analysis of technical manoeuvres or postural strategies adopted by riders could describe in greater detail the model of performance, identify potential counterproductive behaviours, and suggest more specific direction for training. Physiological investigations are needed to deepen the understanding of muscular demands of racing, validating training methodologies and verifying strategies to reduce the impact of heat on rider's performance. Furthermore, studies focusing on the psychological demands of racing and the characteristics of top level performance are needed, as this would improve the understanding of the mental skills necessary to succeed.

Motorcycling Federations, racing organizations, manufacturers and other bodies involved in the sport should consider the short and long-term benefits of providing evidence-based applications of training methods or formulating discipline-specific guidelines for preparation practices, to advance the competitiveness and safety of their affiliated racers. Although the contribution of the rider on the final result of a race remain unmeasurable, it is undeniable that at the chequered flag the human factor counts; therefore advancing the knowledge on the human performance of motorcycle circuit racing riders is a fundamental move to develop the sport by increasing the abilities and safety of their athletes.

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Appendices

Appendix A

AUTEC Secretariat

Auckland University of Technology
D-89, WA505F Level 5 WA Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

16 September 2015

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **15/327 Preparation practices of riders competing in motorcycle road racing**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 15 September 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 15 September 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 15 September 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Emanuele D'Artibale edaworld@gmail.com, Paul Laursen

AUTEC Secretariat

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1 October 2015

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **15/330 Measure of psychological skills via TOPS2 in road race motorcycling riders.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 30 September 2018.

We note that the translations are pending.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 September 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 30 September 2018 or on completion of the project.

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All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Emanuele D'Artibale edaworld@gmail.com, Paul Laursen; Tony Oldham

AUTEC Secretariat

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26 April 2016

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **16/92 Core temperature and pre-cooling strategies in road race motorcycling competitions.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 20 April 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 20 April 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 20 April 2019 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

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To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Emanuele D'Artibale edaworld@gmail.com, Paul Laursen

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27 April 2016

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **16/109 Inertial stress of riders via kinematic analysis in road race motorcycling competitions.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 27 April 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 27 April 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 27 April 2019 or on completion of the project.

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To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

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Appendix B

Optimising the human performance in road race motorcycling

AUT – WIL Sport Research Project

If we want to simplify, successful racing is going faster and braking later.

Indeed, handling quick accelerations (throttle and power) and abrupt decelerations (brakes) are the key elements for a competitive lap-time.

Positive and negative accelerations (increasing speed when exiting corners and decreasing speed when entering them) translate into external forces, requiring muscular activity from the rider.

In conclusion, <u>a rider going faster will experience higher external forces which means higher muscular stress</u>.

The following infographics show the GPS measurements collected in Imola, Donington and Misano, and help understand the efforts needed to race (estimated forces acting on the rider when increasing and decreasing speed during a lap).

Such measurements highlight the importance of physical conditioning and suggest that being stronger per kg of body weight will assist you in going faster.

For further information: ***www.wilsport.co.nz***

Emanuele D'Artibale PhD, Performance Specialist, Motorcycle Road Racing; edaworld@gmail.com

SPORTS PERFORMANCE RESEARCH INSTITUTE, NEW ZEALAND
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Is this track physically demanding?

Circuit: **Imola (ITA)**

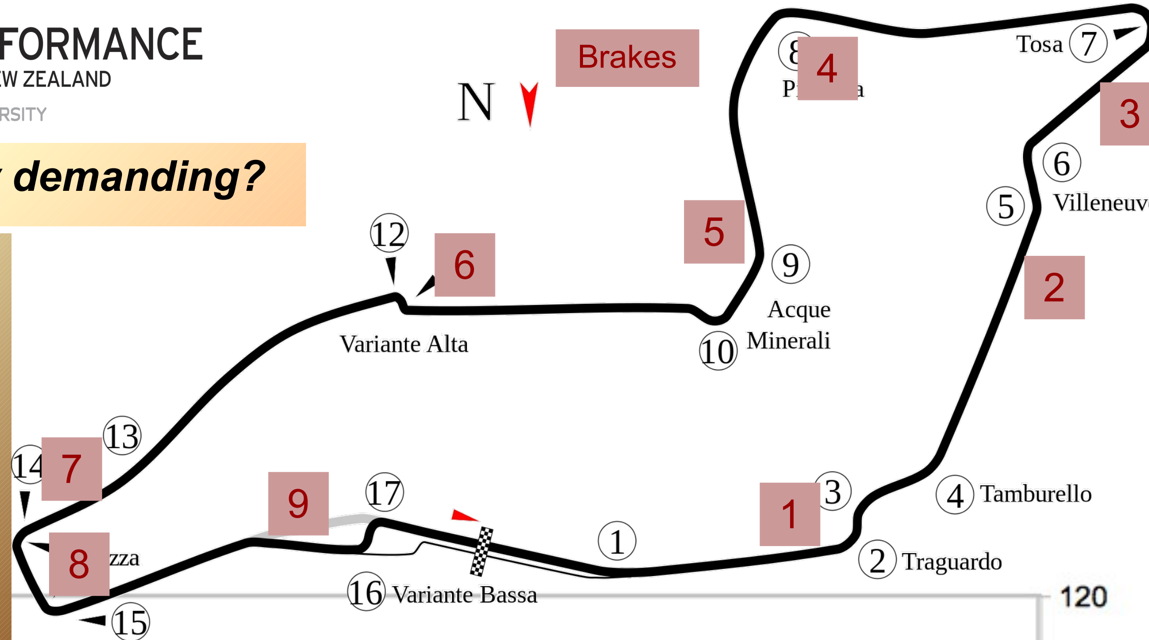
Class: European SuperSport 2016

Lap time here: 1'54"4 (Pole Position 1'51"1)

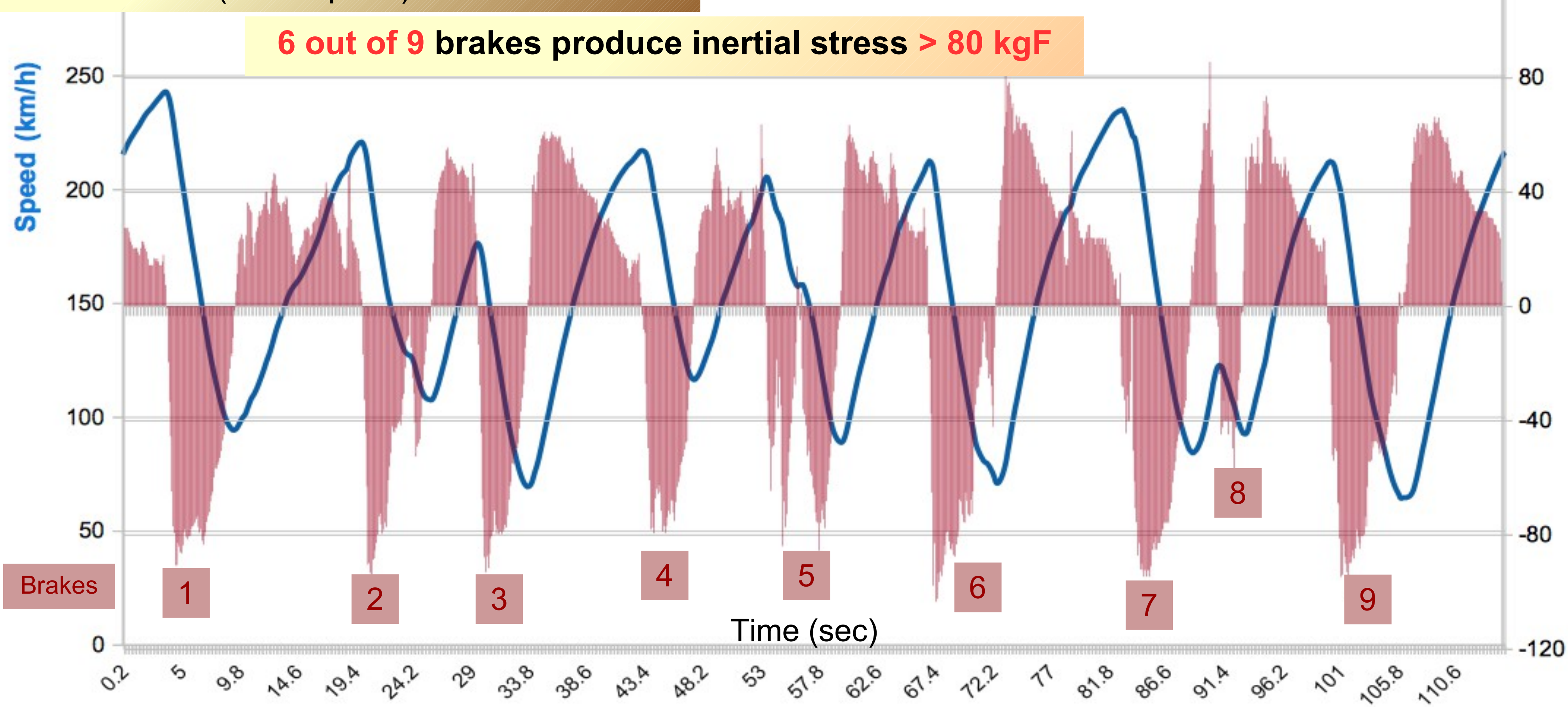
Rider body mass with full equipment: 83 kg

Race Length: 17 laps **(153 braking actions)**

Race Duration (1'52"3 pace): **31 mins 50 secs**



6 out of 9 brakes produce inertial stress > 80 kgF



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RESEARCH INSTITUTE, NEW ZEALAND
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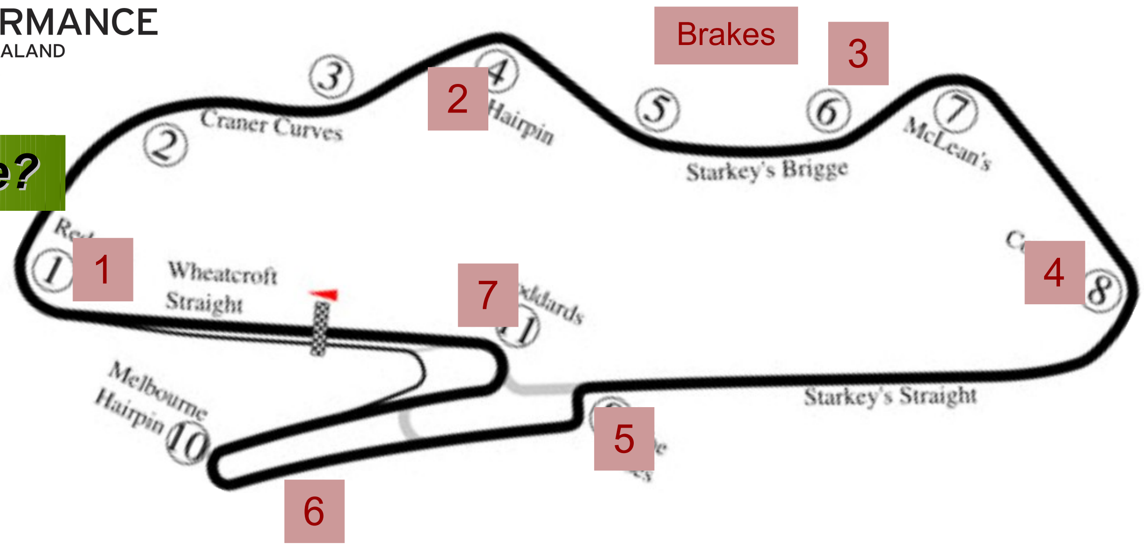


What's the muscular stress of racing here?

Circuit: **Donington Park (UK)**

Class: **European Junior Cup 2016**

Lap time shown here: 1'39"3 (Pole Position 1'38"2)

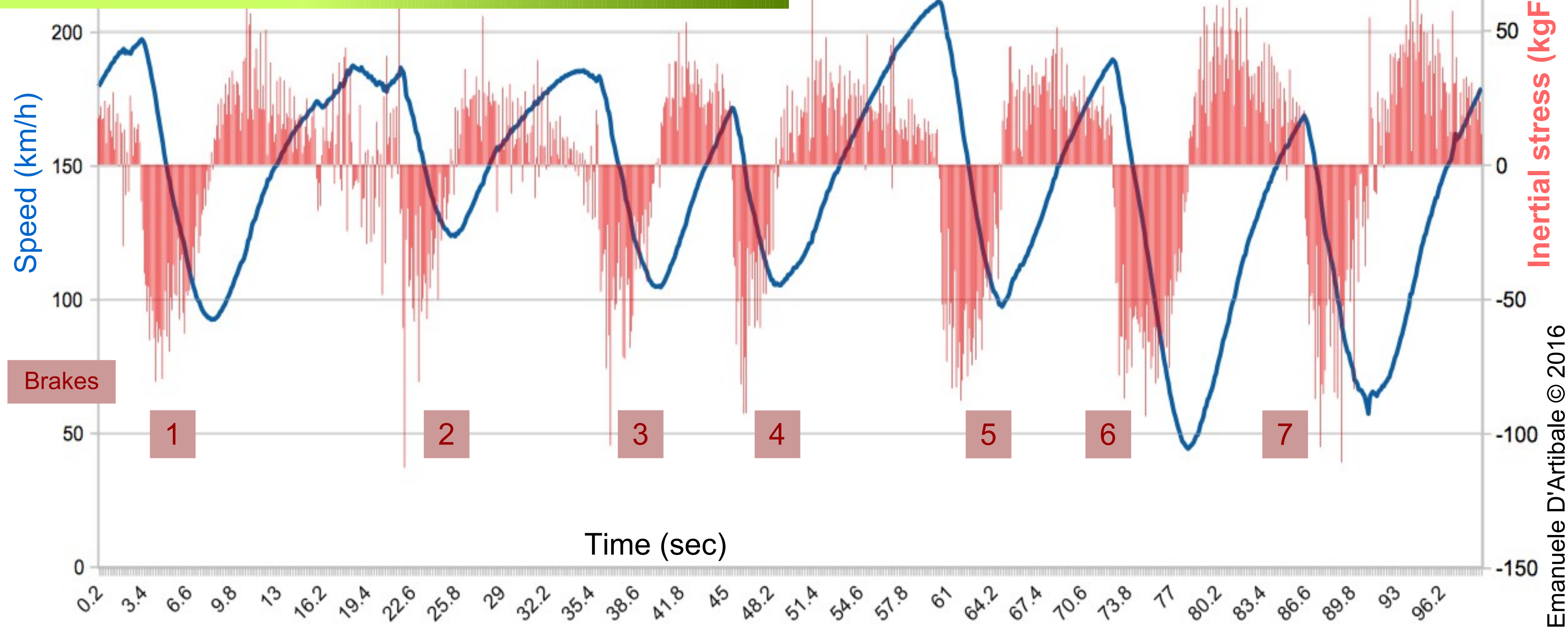
Rider body mass with full equipment: 71.6 kg

Race Length: 11 laps (77 brakes)

4 out of 7 brakes decrease in speed > 100 Km/h

WSBK Pole lap: 1'26"712 – race 23 laps (161 brakes) !!

About 5 push-ups each lap, 55 in a EJC race



Is the stress different between categories?

Circuit: **Misano World Circuit (ITA)**

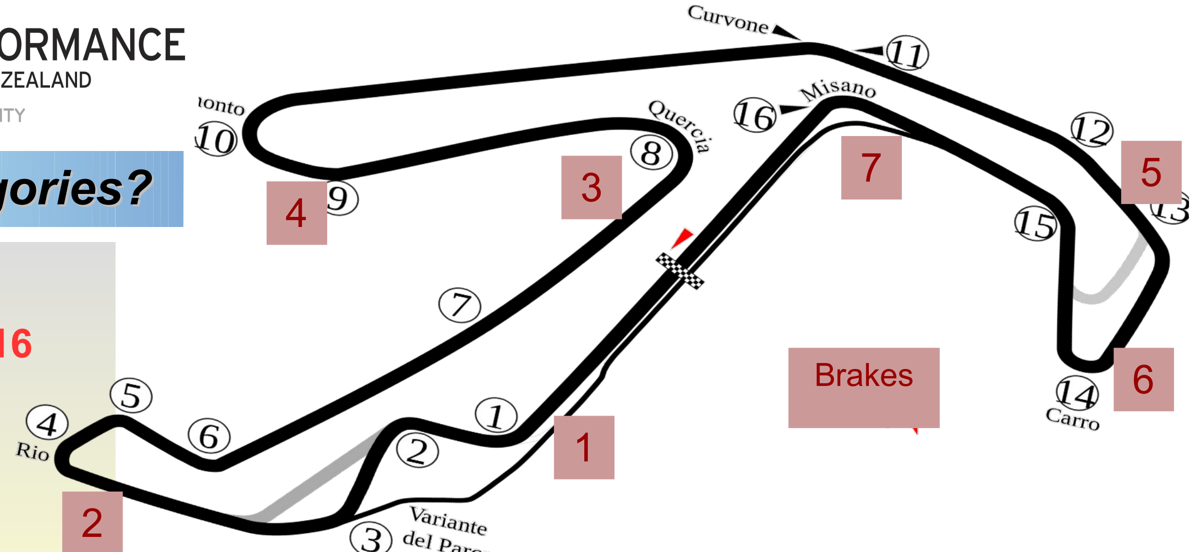
Class: **European Supersport and Junior Cup 2016**

Body mass with full equipment, both rider: 73 kg

Lap time shown here: **SS: 1'42"8 EJC: 1'47"3**

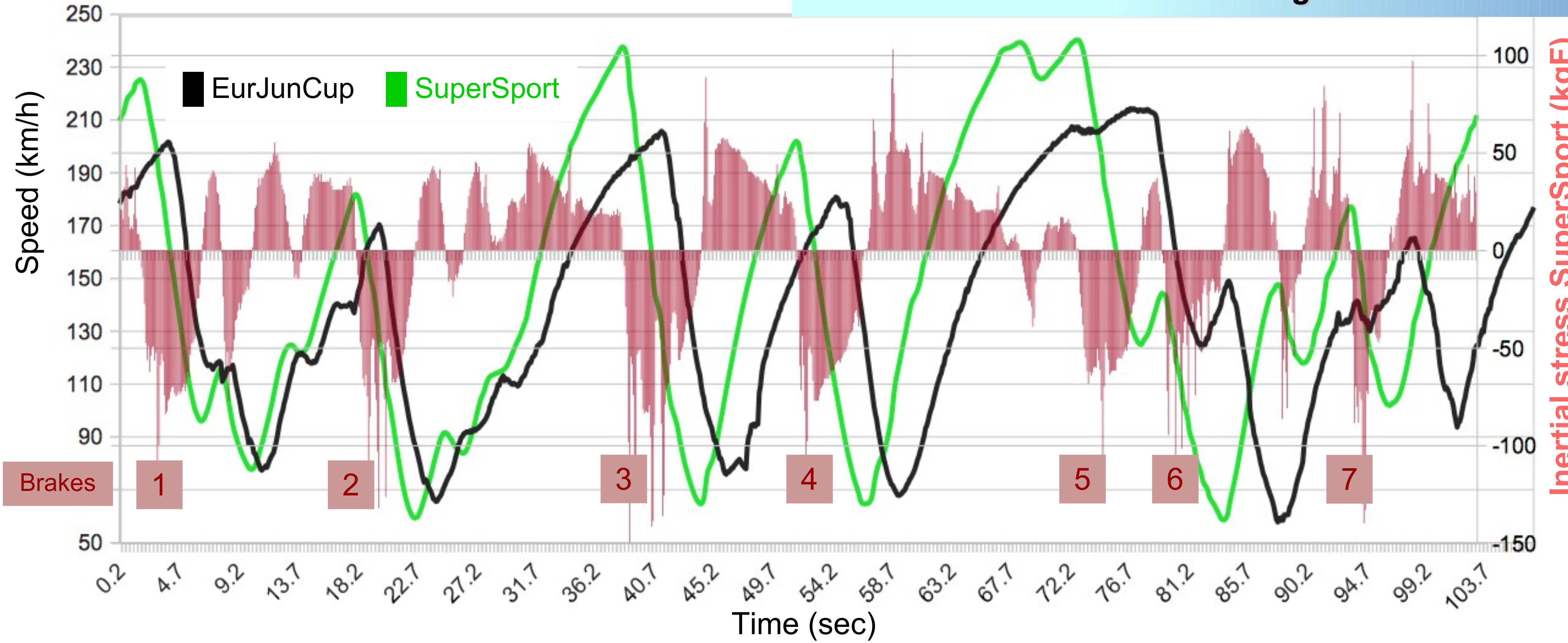
Race: **SS: 19 laps (133 brakes)**; **EJC: 11 laps (77 brakes)**

WSBK Pole lap: 1'34"037 – race 21 laps (147 brakes)



From EJC to SS:

lap time	***- 4.2 %***
muscular stress while braking	***+ 3.3 %***
muscular stress while accelerating	***+ 3.5 %***
counts of braking actions	***+ 73 %***



What can I do to be physically prepared?

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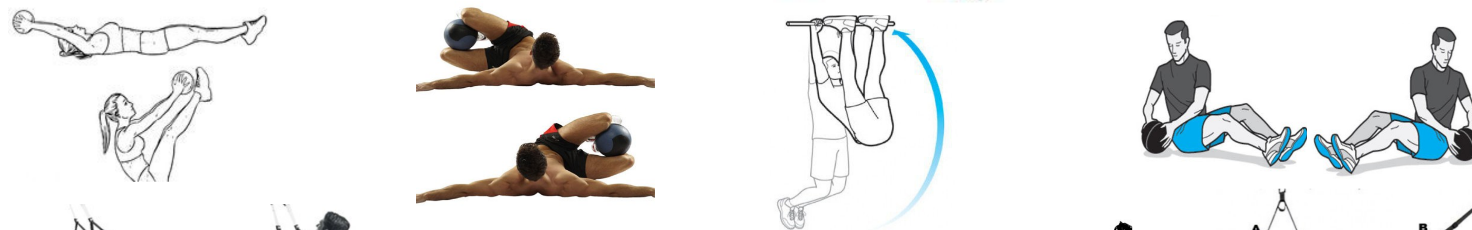
Muscular strength training

PLANK variations static and dynamic

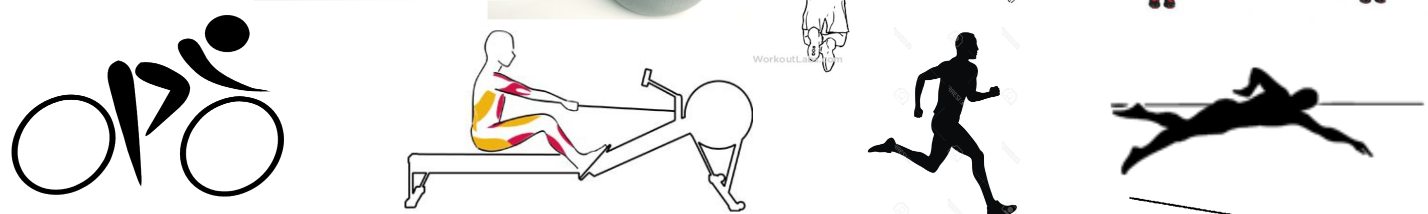
SQUAT variations multiple range of motion

CORE stability

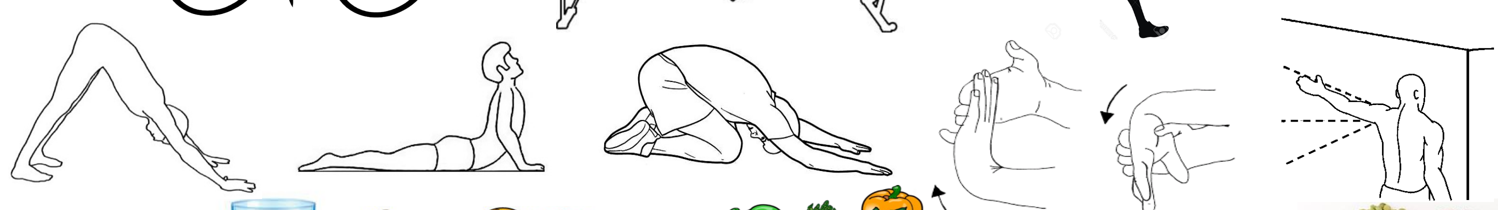


PUSH & PULL patterns

Cardiovascular training



Flexibility



Optimal body composition

Workout minimum 60 mins 3 times per week

Plan properly

Progress accordingly

Get professional advice

Appendix C

Participant Report

Thank you for participating in this study!

You are receiving this report because you have requested so following the online Test of Performance Strategies for road race motorcycle riders.

Why using the Test of Performance Strategies?

The Test of Performance Strategies was designed to measure a comprehensive range of psychological skills and techniques, and their strategic use by athletes both in competition and at practice (Hardy, Ross, Thomas et Murphy 2010). Subscales were developed targeting eight of the most significant psychological skills and processes thought to underlie successful athletic performance:

1. Goal Setting

What does it mean? It's about measurable improvement: setting specific 'focus points' that will take your performance from where you are right now to where you want to be, setting targets for your performance and then turning these into achievable bite-size chunks.

Why does it matter? Most riders have aspirations: but if you can break these down into things you can control and work on daily, you can track your progress, and stay focused on what matters most. Research shows that good goal setting often improves performance…but only when you stick to it!

Example: Aiming to decrease your split time by 2% in sector 3 of the track where you are slower than the majority of your competitors. Aiming to slightly move forward your braking mark in turn 6 without changing the point of apex etc.

2. Relaxation

What does it mean? It's about managing the tension: being able to avoid the negative stress that pressure can cause. A rider aware of his/her state and able to modify it to avoid anxiety can improve performance.

Why does it matter? By nature, racing increases tension (internal factors e.g. heart rate), and the pressure of external factors (financial/sponsors included) can magnify this tension and increase the likelihood of mistakes. A rider needs to make quick decisions and subsequently act with precision; obviously anxiety does not help at all, creating confusion, uncertainty and early fatigue.

Example: Being able to recognize and reduce unnecessary muscular tension while cornering a hairpin, or reduce the mechanical stiffness of your upper body when exiting an uphill turn to ride smoother. Being able to clear your mind and find a balanced state before the race or when a fast lap is required during the last minutes of the qualifying session etc.

3. Activation

What does it mean? To optimally perform, an athlete should be in an ideal state of arousal: not to excited or stressed, not too relaxed or sleepy. A real champion is able to keep calm in stressful situation as well as activate his/her state of arousal to increase their energy level when it is needed.

Why does it matter? During a race, especially shorter ones, a rider is required to be at the right level of activation/arousal from the beginning to the end. There is no opportunity to relax or warm up. When the starting light goes off, the rider needs to be ready to go on his/her fast pace from the first corner, and if you are not ready, it will be difficult to catch the leaders.

Example: Towards the end of a free practice session, although other riders are slow and the atmosphere is laid-back, you are able to set your mind in "race mode" and test yourself and the tyres with consecutive lap-times at race pace. Although race conditions or events (grid position, bike setup, etc.) are unfavorable, you can psych yourself up to reach the right intensity level to race well and be competitive etc.

4. Imagery

What does it mean? It's the visual and multi-sensory mental practice (can include real-experience body feel, movement feel, sounds, etc.), because it's about recreating in your brain an experience that mimics the performance. Mentally you can create any performance setting and can vividly experience any racing situation to increase your awareness, and learn from it.

Why does it matter? Racing experience and riding practice allow you to develop both cognitive and physical skills. Imagery allows you to be exposed to these situations without performing the task. Riders can focus on specific aspects, recreate and repeat them to learn how to solve them. Riders can practice techniques, reflect on solutions, and build confidence with no risk.

Example: Repeatedly mentally imaging sector 2 of the track and going over all the technical skills and movements required, including the feeling of the “bike's behavior”, so as to achieve an optimal line and a quick split time. Recreating in your mind the starting grid and all the happenings of the start, experiencing the lights going off and practicing the actions to approach turn 1 in the ideal manner etc.

5. Self-talk

What does it mean? It’s about what athletes say to themselves, overtly or silently. Consciously or unconsciously, we talk to ourselves and around a performance we say messages of instructional or motivational content, which may contribute to our self-efficacy.

Why does it matter? What we hear and what we say can affect our emotions as well as our concentration. Before or during a performance, instructional messages can affect the completion of actions and motivational words can influence our approach, hence overall performance can be modified.

Example: “Today I am fast, track is warm and I feel great. I have trained really hard lately and I am going to be really fast today!”. Or, at the 100 sign, saying to myself: “slip back while hard brake, down two (gears), stay inside!” etc.

6. Emotional Control

What does it mean? What happens around us and what people do and say can generate in us conscious or unconscious responses. Also in a competitive environment there are things that change our mood and can lead to disappointment, anger, happiness or excitement. Being able to regulate the impact of emotions in a competition setting is a practiced skill for most athletes.

Why does it matter? Emotions are thought to be linked with behaviors and human performance. Anger, sadness or fear can lead to mistakes in your actions and prevent you from performing at your best. Can you recall any top-level rider frustrating an opponent to cause a mistake?

Example: The frustration caused by a comment from your mechanic leads to mistakes in your riding style (missing gear, marks, corner apex). The over-excitement of approaching the last lap of a race while being in a top position causes inaccuracy in your racing lines etc.

7. Automaticity

What does it mean? You probably never have to think about how to tie your shoe laces. It's a complex skill you “programmed” into your brain as a kid. You can now do it without thinking (or worrying) about it. The same with racing: automaticity is about effortless skill execution, with very little active focus on well-known tasks.

Why does it matter? Thinking is often slow, and can get in the way. When skills are automatic, you free your mind to focus on other important aspects of racing... like line and timing.

Example: Realizing that the change of direction at the end of sector 2 comes really natural to you and you feel the bike flowing into it quickly and smoothly. At the end of the main straight, braking and correct downshifting happens easily, and being able to focus only on the line without putting effort in processing the actions to enter the turn correctly etc.

8. Attentional control

What does it mean? In a competition setting, there are many things happening at the same time and getting distracted from important tasks is very easy. Having control of your focus and maintaining mental activity on aspects or processes that are relevant to the race is an important attribute for optimal performance.

Why does it matter? Staying focused allows you to improve your understanding of what is important and thereafter find ways for improvement. At race pace, maintaining your attention on what really matters can make the difference in lap time.

Example: In a new track, during a free practice session before qualifying, you are using a few laps to optimize the gears, but at some point you start to focus on braking marks and lines of the rider in front of you and do not build enough confidence with your own setup. While you are riding to improve your suspension settings and your lines in a training session, you keep thinking about the financial instability that your racing career is experiencing because of the lack of consistent sponsorship etc.

9. Negative thinking

What does it mean? It's having a pessimistic attitude, talking or imagining your performance in terms of negative outcomes. A rider having a negative internal dialogue or recurrent thoughts of failure.

Why does it matter? How can you succeed if you are the first one to not believe in yourself? Thinking negatively or imagining failure can impede, overwhelm or deter a rider's performance.

Example: “I hate this part of this track, I am slower than (name opponent) and if I keep pushing sooner or later I am going to crash here”. “I keep missing the braking marks and the right lines in here and there, my exit speed sucks and I am never going to catch the leading group!” etc.

Where do I stand?

The table below shows your results (xxxxxxxx@xxxxx.com) in comparison with some normative data and results published by other researchers.

	Practice							
	Emotional Control	Activation	Relaxation	Self-Talk	Goal Setting	Imagery	Automaticity	Attentional Control
You	**1.5**	**3.25**	**2**	**3.25**	**3.5**	**2.5**	**4.25**	**3**
Normative data from different sports (n=565)	3.42 ± 0.76	3.41 ± 0.63	2.18 ± 0.83	3.35 ± 0.80	3.24 ± 0.89	3.02 ± 0.82	3.47 ± 0.65	3.44 ± 0.66
Amateur road racing car drivers (n=55)	3.77 ± 0.66	3.46 ± 0.58	2.12 ± 0.88	2.98 ± 0.91	3.65 ± 0.64	3.36 ± 0.77	NA	3.68 ± 0.55
US medalist at Sydney Olympics (n=52)	3.61 ± 0.59	NA	2.49 ± 0.98	3.66 ± 0.64	3.54 ± 0.88	2.95 ± 0.86	NA	3.69 ± 0.55

	Competition							
	Emotional Control	Activation	Relaxation	Self-Talk	Goal Setting	Imagery	Automaticity	Negative Thinking
You	**1.25**	**3.75**	**3**	**3**	**3.5**	**2.75**	**3.75**	**2.25**
Normative data from different sports (n=565)	3.69 ± 0.83	3.84 ± 0.70	2.80 ± 0.94	3.42 ± 0.86	3.73 ± 0.86	3.49 ± 0.94	3.52 ± 0.63	2.23 ± 0.77
Amateur road racing car drivers (n=55)	4.15 ± 0.65	3.41 ± 0.69	2.65 ± 0.80	2.9 ± 0.99	3.86 ± 0.80	3.24 ± 0.91	NA	1.88 ± 0.57
US medalist at Sydney Olympics (n=52)	4.02 ± 0.52	3.92 ± 0.64	3.83 ± 0.60	3.71 ± 0.82	3.94 ± 0.81	3.59 ± 1.07	3.44 ± 0.73	1.91 ± 0.51

So what now?

You can use this report as a guide to improve your performance. With this information, you can focus on those areas that may need improvement, however, if you feel that you need dedicated and specialist advice you should contact a licensed sport psychologist.

For a deeper understanding of the psychological skills applied in sport performance and their potential development you can check these textbooks: *The Sport Psych Handbook* by Shane Murphy, Human Kinetics 2005 or *Mindfulness and Sport Psychology for Athletes* by Kristine Eiring and Colleen Hathaway, DC Madison 2010.

In case you are interested in connecting with a registered sport psychologist you can contact Campbell Thompson at AUT Millennium High Performance Sport New Zealand, 17 Antares place, North Shore Auckland, campbell.thompson@hpsnz.org.nz or contact the principal investigator for a referral.

Whom do I contact for further information about this research?

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Appendix D

Training/practice riding the motorcycle

How: Midi-bike, small motard, flat bike. Riding in go-kart tracks, major circuit parking lot, flat area, airport, asphalt or flat dirt. Establishing special arrangements with circuits, tracks or facilities to facilitate access and participation. Circuit promotions. For motocross, criteria apply.

How often: Min. 60'/wk riding in small sized conditions: in and off season. 120'/mth normal conditions: off season. Pre-event additional practice (60' norm size conditions): in season. 2 annual collective camps per season. Weather conditions may affect programming.

With who: Certified coach programming progressive technical exercises and teaching technical elements in isolated and variable conditions.

Physical Training (without the motorcycle)

How: Individualized training programs aiming at improving muscular strength & endurance, cardiovascular fitness, flexibility, motor control, coordination, react time and balance. Nutritional regimen, hydration, sleep, potential supplements must aim at optimizing body composition, rest and overall health.

How often: 180'-240'/wk = 3-4 physical training sessions without the motorcycle: off season. 60'-240'/wk sessions according to race calendar: in season. Warm ups & flexibility sessions: 60'-120'/wk race week: in season.

With who: Certified trainer, specialized S&C coach: professional recording physical evaluations and programming activities with specificity and balancing physical components. Nutrition expert for meals management.

Mental Training (without the motorcycle)

How: Individualized, mainly 1 to 1 programs aiming at increasing awareness and potential of cognitive mechanisms involved with racing. Goal setting, imagery, relaxation, focusing, self-talk, emotional awareness and control, communication strategies. Team-work analysis.

How often: 60'-300'/wk mental training sessions outside and over riding sessions: off season. 60'-240'/wk sessions according to race calendar: in season. Briefings and feedback analysis during race week as needed: in season.

With who: Sport psychologist, specialized mental coach: professional monitoring activities & feedbacks, programming activities with specificity.

Injury prevention practices

How: Crash-skills programs aiming at progressively increasing awareness, decision making and behavior during crashing events. Riding-load specific flexibility activities in physical training programs.

How often: 60'-90'/wk training sessions: in & off season.

With who: Qualified coach, gymnastics coach: professional designing programs & activities with specificity.

Demographic

How: Promotion of sport discipline for younger population, regulations and series aiming at facilitating access and recruitment. Educational programs, camps, workshops, academies aiming at improving skills and approaches of young riders.

With who: Sport managers teamed with qualified coaches and successful riders.

Support, cooperation, partnerships with facilities. Agreements with: tracks, circuits, gym, training areas, offices: facilitate access. Activities connected with promotion of circuits, administrations, companies, and long term benefits (i.e. circuits).

Rider's Preparation minutes per week	
From	to
90	180
180	360
60	360
60	90
total minutes	
390	990
hours per week	
From	to
6.5	16.5

Creating a team of professionals around the rider. Rider's development ultimate goal. Management, team building, organization, definition of roles.

Private companies, agencies, manufacturers, organizers, national or international federations.