FITNESS, INJURY, AND TRAINING PROFILES OF SOUTH AFRICAN MOTORSPORT DRIVERS

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DECLARATION

I, Christa Botma, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
BMI	Body Mass Index
BPM	Beats Per Minute
CKCUEST	Closed Kinetic Chain Upper Extremity Stability Test
G-Force	Gravitational Force
GT	Grand Touring
HREC	Human Research Ethics Committee
METs	Metabolic Equivalents
NASCAR	National Association for Stock Car Auto Racing
NMQ	Nordic Musculoskeletal Questionnaire
PAR-Q+	Physical Activity Readiness Questionnaire
WHO	World Health Organisation

ABSTRACT

Background

Motorsport is an expanding global sport, yet there is a lack of scientific literature in the field of sports medicine addressing the physical and physiological demands affecting driver-athletes. Internationally, research on this population of athletes is scarce, and there is currently no published literature in South Africa.

Aim and Objectives

We aimed to describe the fitness, injury, and training profiles of South African motorsport driver-athletes. The objectives were to describe the demographics, training history, and injury history of South African motorsport driver-athletes, as well as their cardiovascular fitness, upper and lower body strength, coordination, and reaction times.

Methods

Adult male and female motorsport driver-athletes competing in circuit car racing at social, club, regional, or national level were included in the study. We used a self-developed online survey to collect the demographic characteristics, sport-specific information, training history, and injury history of driver-athletes. A case series of a small cohort of driver-athletes reported on physical tests to determine the upper limb strength, lower limb strength, reaction time, coordination, neck strength, and cardiovascular fitness.

Results

Fifty-one survey responses were included for analysis (three females and 48 males, mean age of 45 ± 16 years; median 13-14 years of driving experience). The main category of circuit car racing that respondents participated in was Clubmans.

It was uncommon for respondents to practice on a circuit outside of race days, with 43% (n=22) practicing less than once a month on a circuit. Nine participants (18%) engaged in coordination exercises, 20% (n=10) in reaction time exercises, and 24% (n=12) incorporated neck strengthening exercises into their routines. Sixty-five percent (n=33) did not include any warm-up or stretching in their pre-race routine, but 75% (n=38) spent time visualising and mentally rehearsing before a race. Sixty-three percent (n=32) of respondents met the WHO guidelines for physical activity in adults. Fifty-five percent (n=28) engaged in regular strength training, 57% (n=29) participated in cardiovascular training, and 25% (n=13) included flexibility exercises in their training regime.

A total of 31 injuries were reported, with the foot/ankle being the most common injury area and fractures the most common injury type. Forty-two percent (n=13) of injuries were sustained during a car accident. Among the 13 injuries sustained during car accidents, 62% (n=8) occurred during competition.

In the case series, all seven participants were male (with mean age: 40 ± 14 years). Three participants competed in the Sports & GT category of circuit car racing. There were no significant differences in left and right-sided measurements for plantarflexion strength, grip strength, lower limb coordination, or reaction times among the participants. For the neck flexor endurance test, the sample exhibited a wide range (range:30-122 seconds). The mean estimated VO_2 max was 30 ml/kg/min (range: 26-36 ml/kg/min).

Conclusion

Many driver-athletes do not engage in regular motorsport-specific training regimes or regular strength and cardiovascular training. This was highlighted in the case series where participants generally exhibited poor fitness and physical conditioning. This cohort of driver-athletes may have placed stronger emphasis on psychological and mental readiness than physical readiness for competition. Our research has provided valuable insights into the fitness, injury, and training characteristics in a cohort of South African driver-athletes. It underscores the importance of promoting awareness of physical fitness and conditioning as essential components to address the physiological and physical demands experienced by driver-athletes in motorsport.

CHAPTER ONE: INTRODUCTION AND SCOPE OF DISSERTATION

1.1 Introduction

Motorsport is defined as "a group of competitive sporting events involving the use of motor vehicles and motorcycles" (Merriam-Webster, n.d.) and encompasses a diverse range of disciplines. These disciplines may include, but are not limited to, off-road racing, oval racing, circuit car racing, rallies, cross country, and motocross, often involving various types of vehicles. Motorsport is a global phenomenon, with driver-athletes competing at professional, amateur, and recreational levels in a wide range of cars and motorcycles (Deakin *et al.*, 2017). In South Africa, motorsport events take place throughout the year, with driver-athletes participating in multiple events within a single season. It's important to note that various motorsport disciplines and racing categories incorporate a diverse array of car types and rules, influencing the dynamics of the racing environment. Therefore, it can be hypothesised that the physiological and physical challenges for each category of racing differs (McKnight *et al.*, 2019). This study focuses specifically on driver-athletes engaged in circuit car racing in South Africa.

According to Ferguson (2018), motorsport enjoys a widespread global popularity, and celebrities affiliated with elite auto racing series such as Formula 1 represent only a minor segment within a much larger industry. A multitude of participants are engaged in lower-level racing across the world (Reid and Lightfoot, 2019). Despite the widespread popularity of the sport, there is a noticeable lack of scientific literature in the field of sports medicine addressing the physical and physiological demands encountered by driver-athletes (Raschner, Platzer and Patterson, 2013; Backman *et al.*, 2005; Ferguson, 2018). The demographics of driver-athletes have evolved greatly in recent years. Potkanowicz (2019) noted that drivers have begun competing at younger ages and continue to regularly compete well into their 40's, 50's, and beyond. Furthermore, motorsport has seen an increase in female drivers at both amateur and professional levels (Reid and Lightfoot, 2019; Potkanowicz and Mendel, 2013).

1.2 Physical Fitness Components in Motorsport

As race cars have become more technologically advanced and the speeding capability of cars have increased (Ferguson, 2018), the physical fitness of driver-athletes plays an increasingly important role in racing safety, competitive pace, and performance (Ebben, 2010; Ebben and Suchomel, 2012; Hoyes and Collins, 2018; McKnight *et al.*, 2019).

Driver-athletes sustain musculoskeletal injuries that are caused by a number of factors including high gravitational forces (G-forces), vibrations, and shocks from the car (Backman *et al.*, 2005; Baur *et al.*, 2010), as well as the physical demands of steering and controlling the car (Ebben and Suchomel, 2012).

Hoyes and Collins (2018) found that coordination, upper body strength, cardiovascular fitness, and reaction times were perceived as the most important fitness components by motorsport driver-athletes, coaches, and fitness trainers. Wertman, Gaston and Heisel (2016), and the Stock Car Driver Survey conducted by Ebben and Suchomel (2012), identified that the most prevalent physical demands experienced by driver-athletes included neck strength, upper body strength, core strength, and lower limb strength. Shoulder fatigue, arm soreness, hand fatigue and soreness, and neck pain were some of the most common complaints among driver-athletes (Ferguson, 2018; Minoyama and Tsuchida, 2004). The experience of the driver, i.e., their skill level, is considered to be am positive contributor to injury avoidance (Baur *et al.*, 2006) and, as such, physical fitness is key to preventing musculoskeletal injuries in driver-athletes (Hoyes and Collins, 2018). Additionally, higher fitness levels have also been shown to speed up recovery time after injury (McKnight *et al.*, 2019; Minoyama and Tsuchida, 2004).

Very little research regarding this group of athletes has been conducted internationally and there is currently no published literature available in South Africa. Therefore, it is essential to consider the injuries of the sport, the demands of the sport, and the training practices of driver-athletes, and to apply this information to the South African context (Ebben and Suchomel, 2012). Investigating the demographics and profiles of driver-athletes in South Africa is crucial for a better understanding of this athlete population.

1.3 Theoretical Framework

Injury prevention research forms an important component of motorsport to reduce the potential impact of injuries on driver-athletes. According to the injury prevention model outlined by van Mechelen (depicted in Figure 1), there are four stages that require careful consideration. The first step of injury prevention involves determining the extent of the injury problem (van Mechelen, Hlobil and Kemper, 1992). While the injury profile of South African motorsport is largely unknown, and the injury burden is not well documented, it is believed to be substantial.

Upon establishing the epidemiology of the injury, the second step involves the identification of factors contributing to the injury. Some retrospective information regarding the injury problem does exist, placing the present study somewhere between step one and two. During step two, the aim is to understand the aetiology of injuries in South African motorsport. Understanding the factors influencing injuries may enable us to target the modifiable risk factors such as fitness and strength, to mitigate the risk of injury as well as to prevent injuries (Backman *et al.*, 2005). Injury prevention strategies (stage three) typically include exercise interventions targeting modifiable risk factors such as strength, fitness, and endurance. In motorsport, physical fitness plays a crucial role in preventing musculoskeletal injuries among driver-athletes (Hoyes and Collins, 2018). Ultimately, it is hoped that this research will lay the foundation for future research in injury prevention to address step three and four of the injury prevention model.

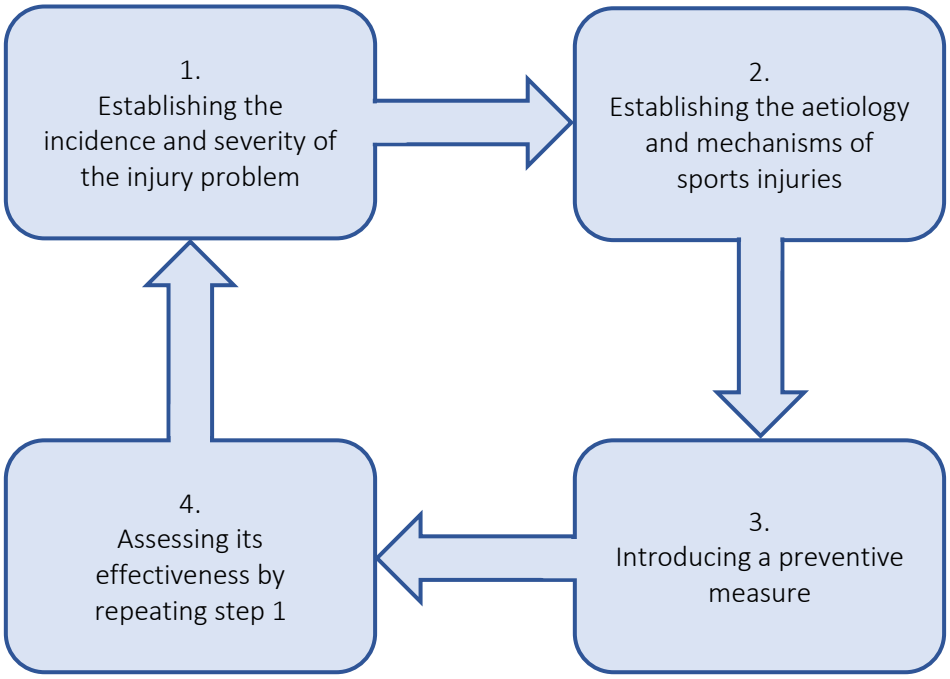

Figure 1. van Mechelen Model of Injury Prevention (adapted from van Mechelen et al., 1992).

1.4 Purpose Statement

The purpose of this study was to investigate and describe the fitness, injury, and training profiles of South African motorsport driver-athletes. This research provides greater insight into the specific areas that driver-athletes should prioritise to mitigate injury risks and enhance their performance. A better understanding may also allow healthcare professionals to develop effective injury prevention strategies and to make well-informed decisions regarding treatment and return-to-race following injuries (Reid and Lightfoot, 2019; Wertman, Gaston and Heisel, 2016).

Furthermore, this study also sought to raise awareness on the importance of physical conditioning for driver-athletes in the context of South African motorsport, which may inform future research in this domain. From a clinical perspective, this research holds the potential to provide guidance to healthcare practitioners in both assessing and treating these athletes. Moreover, it hopes to lay the foundation for the development of training and rehabilitation programmes tailored to the unique needs of driver-athletes.

1.5 Aims and Objectives

1.5.1 General Aim

This study aimed to describe the fitness, injury, and training profiles of South African motorsport driver-athletes.

1.5.2 Specific Objectives

The specific objectives of this study were to:

- describe the demographics, training history, and injury history of South African motorsport driver-athletes; and
- determine the cardiovascular fitness, upper body strength, lower limb strength, coordination, and reaction times of South African motorsport driver-athletes.

1.6 Plan of Development

Chapter Two presents the literature review of the physical and physiological demands of motorsport, injuries in motorsport, and neuromuscular testing in motorsport. The research approach used for this study will subsequently be described in Chapter Three. The findings of the study will be presented in Chapter Four, with a subsequent discussion of these findings in Chapter Five. In Chapter Six, a final summary and conclusion will be offered.

CHAPTER TWO: NARRATIVE REVIEW

2.1 Introduction

The motorsport environment is distinctly unique, characterised by a range of demands that driver-athletes face throughout racing. These demands encompass physiological, psychological, physical, and motorsport-specific challenges, which include coping with high G-forces, enduring shocks and vibrations from the car, and managing heat, among others (Backman *et al.*, 2005). Motorsport comprises a wide array of disciplines, each featuring different levels of participation, varied vehicle types, and diverse events that differ in terms of duration and intensity (Hoyes and Collins, 2018). Despite the increasing participation of female and adolescent driver-athletes in motorsport, these demographic groups remain underrepresented in the existing literature (Deakin and Hutchinson, 2017). Given the continuous growth of motorsport and the diverse demographics of its athlete population, it becomes imperative to attain a comprehensive understanding of the sport's injuries and the physiological and physical demands encountered by these driver-athletes.

As previously mentioned, very little research on motorsport and driver-athletes has been conducted. The limited research on motorsport and driver-athletes posed a challenge for conducting a comprehensive literature review. Therefore, a narrative review design was chosen to summarise the current published literature and to provide an overview of various aspects of motorsport. This narrative review aimed to summarise the current available literature on the physical and physiological demands of motorsport, injuries in motorsport, risk factors for injuries in driver-athletes, injury prevention in motorsport, and neuromuscular testing in motorsport.

A literature search of the PubMed, Scopus, and Google Scholar databases was conducted using the following search terms: (("motorsport” OR "motor sport" OR "automobile sport" OR "auto racing" OR auto-racing OR "motor racing" OR "race car driving" OR motorsports OR "motor sports") AND (fitness OR "physical fitness" OR "physical demand*" OR "physiological demand*" OR injuries OR injury OR trauma)). Only full text articles in English were included in this review and the reference lists of articles were hand searched by the researcher for further articles for inclusion. The literature search was conducted from 25 July 2022 to 1 August 2022, with a follow-up search performed on 19 September 2023.

2.2 Disciplines of Motorsport

Motorsport includes a multitude of disciplines and racing categories on a global scale. In the United States of America, motorsport holds significant prominence featuring a diverse array, including the Indy Racing League, NASCAR (National Association for Stock Car Auto Racing), and the Cart World Series, to name just a few. Oval racing, often referred to as stock cars, navigate circular tracks which distinguishes them from road or circuit courses that encompass both left and right turns (Ferguson, 2018).

In Europe, motorsport includes various disciplines such as Formula 3000, Formula 3, and rallying (Klarica, 2001). Rallying, in particular, is a distinct category within motorsport, involving a driver and a navigator who must complete a series of stages in the most efficient cumulative time, often across diverse surfaces (Turner and Richards, 2015). Australia also boasts a rich motorsport landscape with numerous disciplines, including the Shell Touring Cars, Formula Ford, GTP (Grand Touring Performance), Formula Holden, and the Nations Cup Series. Furthermore, many other countries around the world offer a diverse range of motorsport types and events (Klarica, 2001).

South Africa is no exception and offers various disciplines of motorsport, as outlined in Table 1 below. In 2023, South Africa saw approximately 1195 driver-athletes participating in circuit car racing across various levels, including social, club, regional, national, and international. Among these driver-athletes, 534 held club licenses, 445 possessed regional licenses, and 170 were registered with national licenses. Notably, motorsport in South Africa is predominantly male-dominated, with 1160 male driver-athletes competing in circuit car racing in 2023, in contrast to only 35 female driver-athletes (Monteiro, 2023).

Table 1. Disciplines of Motorsport in South Africa.

DISCIPLINE	DESCRIPTION
Circuit Car Racing	Car racing around a road course or circuit with multiple left and right turns. Categories include: Clubmans, Classic Cars, GTi Challenge, Fine Cars, Formula Libre, Sports and GT, Supercars, V8 Masters, and Rallycross
Circuit Motorcycle Racing	Motorcycle racing around a road course or circuit with multiple left and right turns. Categories include: 1000cc, 600cc, 300cc, 250cc, 150cc, and Supermoto
Cross-country Car Racing	Long distance off-road racing that takes place over several days
Cross-country Bikes and Quad Racing	Quads and motorcycle racing on a set course in a closed environment on agricultural, timber or bush and veld areas
Drag Racing	Two cars or motorcycle riders against each other to see who can cover a quarter of a mile from a standing start in the quickest time
Drifting	The driver employs a combination of throttle control, braking, clutch manipulation, gear shifting, and steering input to maintain the car in a state of oversteer while navigating from one turn to another
Enduro Racing	Tests the reliability of motorcycles and the skill of the rider who must cover an entire off-road distance under prescribed conditions
Kart Racing	Racing around a circuit in Go-karts
Motocross	A form of off-road motorcycle racing held on enclosed off-road circuits
Oval Dirt Racing	Car racing around a dirt oval course with only left turns
Oval Tar Racing	Car racing around a tar oval course with only left turns
Rally Racing	Driver and co-drivers complete multiple stages over multiple days in the shortest possible time

Circuit car racing encompasses various facets depending on the type of car, including saloon cars, single seaters, and historic racing. Driver-athletes in the Western Cape participate in a range of categories of circuit car racing, such as Clubmans, Classic Cars, GTi Challenge, Fine Cars, Formula Libre, Sports and GT, Supercars, V8 Masters, and Rallycross. Clubman's racing is class-based, with various lap times and a cut-off time of 1 minute 21.5 seconds. Beyond this, car weight becomes a formality.

As the car's speed increases, participants move up to higher classes, ultimately reaching Class A where a weight rule applies. Classic cars include saloon cars manufactured before 1977, which are required to retain their original-type engines.

GTi Challenge racing is a one-make series that includes all Volkswagen cars and products. Fine Cars consists of road-legal saloon cars or production sports cars and prototypes manufactured prior to 31 December 1989. These cars must have been out of production for more than a decade, and it is mandatory to preserve the original manufacturer's engine, gearbox, and other running components. Formula Libre is a category that includes all types and makes of single-seater cars. The Sports and GT category accommodates all sports cars and GT makes. Supercars form a one-make series based on the Opel Astra, featuring a tubular space frame chassis and a fiberglass body shell. V8 Masters, tailored for drivers 40 years and older, is also a one-make series utilising identical cars constructed at Killarney International Raceway (Western Province Motor Club, 2022).

Categories range from ‘single-seater’ and ‘open-wheeled’ or ‘open cockpit’ vehicles used in popular international series such as Formula racing and IndyCar, to ‘multi-seated’ and ‘closed-wheeled’ or ‘closed cockpit’ racing, including stock car racing, touring cars, sports cars, and off-road racing (Matthews and Pike, 2016; Seiffert, Szymski and Krutsch, 2020). Saloon cars are four-door cars with their bodies divided into three sections. The front section usually contains the engine, the middle serves as the main cabin for passengers, and the rear section is the boot.

Open-wheel cars typically have single-seater open cockpits that expose drivers to the external environment, with the engine located behind the driver (McKnight *et al.*, 2019; Reid and Lightfoot, 2019). The wheels of open-wheel cars are located outside the bodywork of the vehicle (Reid and Lightfoot, 2019). Closed-wheel cars are similar to manufactured road cars, but are highly modified for racing, with the wheels largely enclosed within the vehicle’s bodywork. These vehicles also expose drivers to longitudinal and lateral G-forces, but driver-athletes face a much greater risk of cardiovascular strain and hyperthermia due to the high temperatures inside closed cockpits (McKnight *et al.*, 2019).

2.3 Physical and Physiological Demands of Motorsport

Driver-athletes in motorsport face a multitude of physical and physiological challenges. Some of these challenges include enduring extended periods of driving and maintaining peak performance, navigating high speeds, coping with the physical demands of steering and braking the car, enduring repetitive G-loading forces, managing cardiovascular and thermoregulatory stressors, and contending with the ever-present risk of serious accidents (Seiffert, Szymski and Krutsch, 2020; Minoyama and Tsuchida, 2004). In addition to the physical and physiological stresses, driver-athletes are also challenged by various mental factors, including the cognitive demands of the sport, emotional stress, and discomfort or pain (Reid, 2022; Matthews and Pike, 2016).

Over time, these recurrent challenges in motorsport racing can lead to adverse consequences such as dehydration, fatigue, heightened metabolic and cardiovascular demands, increased core body temperatures, decreased performance, mental lapses, and an elevated risk of accidents and injuries (Reid, 2022; Matthews and Pike, 2016). It is hypothesised that the physical and physiological challenges differ across various racing categories (McKnight *et al.*, 2019). These divergent challenges stem from the unique demands of each racing discipline, as well as the specific rules and regulations governing them (Reid and Lightfoot, 2019). Backman *et al.* (2005) concluded that these discipline-specific demands lead to distinct adaptation processes for driver-athletes.

2.3.1 Physical Demands of Motorsport

2.3.1.1 Heat

Race cars produce significant thermal energy during racing, with heat emanating from the exhaust system, engine, tires, and brakes. These factors combine to elevated temperatures within the car's cockpit (Reid, 2022). According to the published literature, cockpit temperatures can reach up to 50-60˚C (Reid and Lightfoot, 2019; Seiffert, Szymski and Krutsch, 2020; Reid, 2022). In closed cockpit cars, temperatures can rise as high as 75˚C, leading to core body temperatures rising to 40-41˚C (Backman *et al.*, 2005).

Most driver-athletes wear safety equipment, typically consisting of a fire suit, a balaclava, and sometimes fire-resistant undergarments, in addition to a helmet and fire resistant gloves and boots (Reid, 2022). In these conditions perspiration is profuse, and its cooling effect through evaporation is hindered by the safety clothing (Reid, 2022; Carlson, Ferguson and Kenefick, 2014). The combined effect of multiple protective layers and high cockpit temperatures impairs the driver-athlete's thermoregulatory ability to regulate body temperature (Potkanowicz and Mendel, 2013).

Consequently, driver-athletes may lose 3-4% of body weight during a race due to sweat loss and dehydration (Reid, 2022). Some published literature has reported even higher figures, with driver-athletes losing as much as 5-10% of their body weight during a race (Backman *et al.*, 2005) and it is not uncommon for drivers to lose up to 3.5 kg of sweat during a four hour race (Barthel and Ferguson, 2021). The combined effects of dehydration and heat stress exert severe physiological and thermal strain on driver-athletes. This strain can impair cognition, reduce performance, increase the perception of discomfort and exertion, and in severe cases, lead to heat stroke or loss of consciousness (Reid, 2022).

2.3.1.2 Gravitational Forces

Gravitational forces represent the acceleration experienced by an object in a specific situation. Gravitational forces can be positive or negative and can act in multiple axes (Potkanowicz and Mendel, 2013). Driver-athletes must contend with G-forces produced by the car during changes in velocity or direction (Reid, 2022), where excessive or persistent gravitational loads can pose challenges (Potkanowicz and Mendel, 2013). Lateral G-forces are encountered during corners (Ferguson and Myers, 2018; Reid, 2022), while acceleration and braking produce G-forces along the longitudinal axis (Ferguson and Myers, 2018), and changes in track configuration such as negotiating a banked curve or cresting a hill induce G-forces along the vertical axis (Reid and Lightfoot, 2019). Open-wheel cars expose driver-athletes to longitudinal, lateral, and vertical G-forces, which can increase muscular strain and negatively affect aerobic capacity (McKnight *et al.*, 2019).

Neck muscles undergo significant strain when forces reach 4-4.5 G (Backman *et al.*, 2005), and modern vehicles designed for enhanced aerodynamic downforce can exceed 5 G during braking and cornering (Reid, 2022). Therefore, it's not surprising that one of the most demanding aspects for driver-athletes is the physical effort needed to withstand gravitational loads (Reid, 2022). Gravitational forces typically ranging from 5-10 G can lead to severe injuries, such as fractures and concussions resulting from an abrupt deceleration at speeds of approximately 150-200 km/h (Minoyama and Tsuchida, 2004).

2.3.1.3 Vibrations

Vibrations from the car, which are transmitted to the driver-athlete, can function as localised mechanical stimuli or manifest as whole-body vibrations, both of which elicit physiological responses in the body (Reid, 2022).

Interactions of the car with irregularities in the road can lead to temporary vertical loads imposed on the driver, resulting in discomfort and injuries among driver-athletes (Reid, 2022). Sport-specific overuse musculoskeletal injuries caused by the vibrations of the racing car have been documented (Baur *et al.*, 2006), and back pain in Formula 1 driver-athletes may be as a result of prolonged exposure to vibrations (Mansfield and Marshall, 2001).

Laboratory studies conducted on healthy individuals have demonstrated that whole-body vibrations can trigger an increase in cardiac output, heart rate, oxygen consumption, and minute ventilation. These changes are also observed in the cardiopulmonary responses of driver-athletes during competition (Reid, 2022). It is believed that whole-body vibrations can also lead to mental fatigue. Localised vibrations transmitted through the steering wheel present a well-defined issue, leading to fatigue and cramping in the upper body, arms, and hands, which can impair control of the car (Reid, 2022). Chronic exposure to vibration is thought to be a potential cause of neuropathies and other neuropathic conditions in the arms and hands (Reid and Lightfoot, 2019; Wertman, Gaston and Heisel, 2016).

2.3.1.4 Muscular Stresses

Driver-athletes require sufficient strength and endurance to steer the car, achieve high pedal forces for braking, and to stabilise their bodies and extremities against the G-forces generated (Baur *et al.*, 2006). The driver's body position is maintained and G-forces are resisted through the engagement of muscles in the neck, shoulders, trunk, and back (Barthel *et al.*, 2020). Driver-athletes must also exert significant effort to maintain the correct position of their head, which along with the helmet, has a combined weight of about 6.4 kg while driving (Potkanowicz and Mendel, 2013).

Ebben and Suchomel (2012) conducted a survey of 40 stock car drivers and identified that upper body strength was perceived as the greatest physical demand for stock car racing, followed by cardiovascular endurance, heat tolerance, neck and core strength, and lower body and leg strength. The management of heart rate during racing, along with the prevention of fatigue and the maintenance of focus, requires sufficient cardiovascular endurance. The physical demand of lower body strength is related to braking and operating the clutch while racing (Ebben and Suchomel, 2012). Heat tolerance and lower body strength have previously been demonstrated as common physical demands in open-wheel car and formula driver-athletes. Additional reported physical demands include hand-eye coordination, reflexes, and reaction time, as demonstrated in previous studies involving British sports cars and IndyCar (Ebben and Suchomel, 2012).

Hoyes and Collins (2018) conducted a descriptive study in which they surveyed 110 driver-athletes to investigate the perceived importance and balance of fitness components for motorsport across different formulas and categories. Cardiovascular fitness emerged as the most crucial fitness component, followed by coordination, upper body strength and endurance, and reaction time (Hoyes and Collins, 2018). Cardiovascular endurance and upper body strength and endurance were perceived as very important across all formulas and categories (Hoyes and Collins, 2018). Reaction times and coordination were rated as highly important, particularly in sports cars, touring cars, prototypes, and karting (Hoyes and Collins, 2018).

2.1.3.5 Carbon Monoxide

Carbon monoxide exposure is specific to motorsport and poses a significant challenge for driver-athletes and pit crew members (Ferguson, 2018; Reid and Lightfoot, 2019). This issue is particularly prevalent in race categories where the cars have closed cockpits (Reid and Lightfoot, 2019). Carbon monoxide is a molecule that binds to haemoglobin and hinders the transportation of oxygen to the body's working tissues (Ferguson, 2018).

According to Ferguson (2018), two factors contribute to increased carbon monoxide exposure among driver-athletes: 1) the dimensions and configuration of the racetrack, and 2) the proximity of the car's tailpipe to the cockpit. Smaller oval tracks in particular tend to produce an atmospheric cloud of carbon monoxide fumes as a consequence of repetitive circling of the cars. Carbon monoxide exposure also rises with the race's duration, the closeness of cars, and the number of cars on the track (Reid and Lightfoot, 2019). In competitive racing, strategically drafting behind the lead car is a crucial tactic to reduce aerodynamic drag and enhance performance. When doing this, a pocket of air is towed in tandem with the car, capturing both exhaust gases and carbon monoxide (Walker, Ackland and Dawson, 2001).

Prolonged and excessive exposure to carbon monoxide can lead to acute impairments in controlling tasks, coordination, increased reaction times, and the ability to multitask (Ferguson, 2018; Owen, King and Lamb, 2015). Previous research examining driver performance under carbon monoxide exposure has shown a decline in the ability to accurately assess a car's position within a lane and its relative position to other vehicles. It also leads to an increase in sweat rate and body temperature, intensifying the effects of dehydration and hyperthermia on psychomotor performance (Walker, Ackland and Dawson, 2001).

2.3.2 Physiological Demands of Motorsport

2.3.2.1 Heart Rate

Previous research has indicated that racing drivers sustain heart rates ranging from 65% to 80% of their maximum capacity for durations spanning one to four hours (Ferguson *et al.*, 2019) and the heart rate of driver-athletes has previously been recorded to reach as high as 140-180 beats per minute (bpm) during a race. Furthermore, their energy expenditures are reported to be 8-10 times higher than resting levels when driving under non-racing conditions (Backman *et al.*, 2005; Ebben and Suchomel, 2012). It has been established that the heart rate of driver-athletes increases before a race begins as an anticipatory response, and remains elevated throughout the event (Reid, 2022). Generally, the heart rate elevates with the average speed of the car, but also fluctuates according to the driver's position on the track, being lower on straight sections and higher in corners (Reid, 2022). According to Minoyama and Tsuchida (2004), the heart rate can increase up to 170-180 bpm during cornering.

Potkanowicz and Mendel (2013) reported two possible reasons for the increase in heart rate observed in driver-athletes during racing, namely an increase in physical exertion necessary for competing in motorsports and an increase in sympathetic nervous system involvement. An increase in heart rate could also result from hormonal influences due to anticipation, anxiety, and the competitive nature of the sport (Potkanowicz and Mendel, 2013; Jacobs *et al.*, 2002). In situations where the cardiovascular system is under stress to support muscles and thermoregulation during prolonged physical activity and heat exposure, there is a disproportionate rise in heart rate, even in the absence of an escalation in exercise intensity (Potkanowicz and Mendel, 2013). Heat significantly contributes to cardiovascular stress as it causes an elevation in blood flow to the skin, sweat rate, and heart rate, and increases cardiac output for a given level of physical work (Reid, 2022).

2.3.2.2 Fatigue

Fatigue is a well-known factor that can compromise performance in motorsport and can be caused by driving a car for an extended period of time. Fatigue within motorsport lacks a clear definition, and research in this area remains incomplete, lacking precise quantitative assessments. Due to this ambiguity, the boundary between the symptoms and effects of fatigue is also unclear (Von Jan *et al.*, 2005). In sports, fatigue is commonly described as "a decline in muscular force or power during acute exercise, exercise-induced decline or impairment of performance, or as a decrease in baseline physiological and psychological functioning of an athlete secondary to a chronic increase of the physical and mental load" (Bestwick-Stevenson *et al.*, 2022, p. 1152).

It has also been defined as "a state in which performance capabilities are temporarily impaired by continual activity demands which exceed the ongoing capacity to restore performance capabilities" (Von Jan *et al.*, 2005, p. 2). Azizan, Fard and Azari (2014) identified drowsiness as one of the key indicators of fatigue in their study, examining the correlation between whole-body vibrations in a vehicle and human drowsiness.

In trained driver-athletes, fatigue is unlikely to result from a lack of sleep or stimulation. Instead, it is more likely to be caused by the environmental and sport-specific demands placed on the driver-athlete. This fatigue has significant effects on driver alertness and can lead to a decrease in anticipation movements (Owen, King and Lamb, 2015). Owen, King and Lamb (2015) concluded that an increase in heart rate, temperature, carbon monoxide levels, respiration and whole-body vibrations, and prolonged mental challenges are significant contributors to the mental and physical fatigue of driver-athletes in racing. Dehydration can also increase susceptibility to cramps and fatigue. The physical exertion required to resist G-forces and control the car during a race can lead to muscular fatigue in the legs, trunk, arms, shoulder girdle, and neck, negatively affecting braking, steering, postural control, and the overall performance of driver-athletes (Reid, 2022).

Fatigue is less significant in events of a short duration, such as sprint and drag races, but can have a substantial impact on driver-athletes in longer races and endurance events (Reid, 2022). In endurance racing, where a team of multiple drivers shares one car to cover a large distance in a single event, many of these races last several hours, and each driver typically drives for two to four hours at a time. Endurance racing is one of the most rigorous forms of motorsport, designed to test both the driver and the car over extended periods and through multiple driving stints (Potkanowicz, Ferguson and Greenshields, 2021). Endurance racing places a strong emphasis on the psychological aspect, requiring elite drivers to possess not only physical fitness to endure the strains on their bodies, but also cognitive skills to maintain focus throughout a prolonged race (Ferguson, 2018). Road races in particular require more effort and promote greater fatigue compared to speedway races of a similar duration, primarily due to the frequent changes in direction and speed that road races demand (Reid, 2022).

In summary, the effects of fatigue manifest at physiological, cognitive, and motor levels. Physiologically, it results in reduced psychophysiological stimulation. Cognitively, it diminishes alertness, vigilance, and delays information processing and decision-making. On a motor level, it increases reaction time during critical events, makes controlled reactions more variable and less effective, and ultimately results in reduced preparedness to react (Von Jan *et al.*, 2005).

2.3.2.3 Metabolic Demand

The intense physical strain of motorsport places considerable metabolic demand on driver-athletes (Reid, 2022). This approximately ranges from 5.3 to 13.00 metabolic equivalents (METs), and measurements of oxygen consumption (VO_2) by professional driver-athletes have demonstrated that sustained VO_2 averaged 2.76 $L.min^{-1}$ while driving (Reid, 2022). Previous data has shown that driver-athletes can participate for extended periods, occasionally exceeding 60 minutes, while maintaining a VO_2 max level ranging from 45-79% (Gordon, Thompson and Salisbury, 2010). A further indication of metabolic demand can be seen in elevated blood lactate levels with long periods of continuous driving (Reid, 2022).

Prior studies have noted that young open-wheel driver-athletes, when driving at approximately 130 km/h on a speedway for 28 minutes, displayed a physical activity ratio within the range of 4.9 to 5.4 METs. This aligns with an average energy expenditure of 177.7 ± 21.9 kcal/min, alongside an associated heart rate of roughly 133 bpm (Durand *et al.*, 2015). Durand *et al.* (2015) conducted a study on heart rates during a 24-hour go-kart race in Le Mans, France. Their findings indicated that driving a go-kart for 45 minutes at an average speed of around 60 km/h led to an energy expenditure of 300 kcal, which equated to a 5.6 METs level of effort. This exertion also caused a 73 bpm increase in heart rate, reaching 82% of the driver's maximum heart rate (Owen, King and Lamb, 2015).

This metabolic strain on driver-athletes is a result of high energy demands, as well as increased concentration, elevated sympathetic nervous output, and fluctuations in specific hormones as a result of anxiety and stress (Gordon, Thompson and Salisbury, 2010; Durand *et al.*, 2015). Psychological stress can also have a significant impact on the metabolic demand on driver-athletes (Baur *et al.*, 2006). An elevated metabolism leads to an increase in heat production due to aerobic metabolisms and enhanced blood flow directed towards working muscles (Reid, 2022).

2.4 Injuries in Motorsport

Injuries in motorsport have not been widely researched, and there is still a limited understanding of the injuries sustained within the sport (Minoyama and Tsuchida, 2004). Due to the different vehicle designs and distinct rules and regulations in each category of racing, every motorsport category or class has its own unique demands and, as a result, its own injury patterns (Seiffert, Szymski and Krutsch, 2020). For this reason, it is challenging to generalise motorsport into a single category when reporting on injuries (Seiffert, Szymski and Krutsch, 2020).

2.4.1 Injury Definitions in Motorsport

In motorsport, the definition and classification of injuries are not well defined and are often inconsistent. Injury definitions used in motorsport are outlined in Table 2. In Zasa *et al.* (2016), injury was defined as “the inability to race or train” (p. 290). Tomida *et al.* (2005) provided a more specific definition, describing injury as “the inability to train or compete in national championships” (p. 508). The criterion frequently used to define and assess injury severity is the time lost from practice or competition (Parkkari, Kujala and Kannus, 2001). However, this method of recording injuries may not always be accurate. Using a more sensitive injury definition would help include those injuries that do not necessarily result in time loss and should also be reported (Parkkari, Kujala and Kannus, 2001).

According to the 2020 International Olympic Consensus Statement on recording and reporting epidemiological data on injury and illness in sports, the term "injury" was defined as “tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy” (Bahr *et al.*, 2020, p. 3).

Table 2. Injury Definitions used in Motorsport.

AUTHOR/S	DEFINITION
Zasa *et al.* (2016)	• The inability to train or compete. • Severity of the injury was categorised by the time frame that participants were absent from practice or racing.
Tomida *et al.* (2005)	• Inability to train or compete in national championships. • Severity of injury was categorised by the time absent from race or practice. • Minor injuries were defined as interrupted participation for a period of less than a month. • Major injuries were defined as the absence from participation for more than a month.

2.4.2 Prevalence and Incidence

As noted by Minoyama and Tsuchida (2004), analysing and reporting on the incidence of injuries among motorsport driver-athletes is challenging due to the varying conditions in each category and race. The number of cars or motorcycles in each race varies and the speed of the vehicles differ, leading to differences in injury incidence from race to race. Additionally, there may be distinctions between incidents and injuries involving amateur driver-athletes and those involving professional driver-athletes (Minoyama and Tsuchida, 2004).

In four-wheeled motorsports, the incidence of injuries is relatively low compared to disciplines such as motorcycle or motocross racing. It is estimated that the incidence of injuries in four-wheeled motorsports is approximately 1 per 1000 hours of driving, with most injuries classified as less severe, requiring no complex treatment (Seiffert, Szymski and Krutsch, 2020). While instances of severe direct trauma leading to fatal injuries are infrequent, a notable prevalence of concussions and direct trauma persists, predominantly impacting the neck, head, and lower extremities of driver-athletes (Baur *et al.*, 2006). Injury rates in motocross and motorcycle racing is significantly higher, reported as 22.4 per 1000 hours (Tomida *et al.*, 2005). Zasa *et al.* (2016) reported an overall injury rate of 4.1 per 1000 practice kilometres and 3.8 per 1000 race kilometres in MotoGP motorcycle driver-athletes.

2.4.2.1 Acute Injuries

Driver-athletes are consistently exposed to high-risk situations in motorsport, including car crashes and accidents which may result in acute injuries such as fractures, sprains, concussions, abrasions, and bruising (Minoyama and Tsuchida, 2004). In four-wheeled motorsports, the most common acute injuries are abrasions and contusions, with more severe injuries occurring in traumatic accidents (Seiffert, Szymski and Krutsch, 2020). Minoyama and Tsuchida (2004) reported that 58% of injuries in single-seater car racing were bruises, and 53.2% of injuries in saloon car racing were neck sprains. Head injuries are the most frequent type of injury sustained during traumatic accidents in motorsport events (Gorove, 2012).

In motorcycle racing, prevalent acute injuries include dislocations, fractures, and ligament injuries (Tomida *et al.*, 2005; Zasa *et al.*, 2016). Hay, Singh and Hay (2023) reported that the most common injuries in motocross were clavicle fractures, long bone fractures, forearm/distal radius fractures, and shoulder injuries. When examining the distribution of injuries, the most commonly affected area were the hand and wrist, followed by the foot and ankle, spine, and shoulder and elbow (Hay, Singh and Hay, 2023). Fire and burns have become less prevalent in motorsport in recent years due to improved safety techniques and rule changes (Gorove, 2012).

In a survey of stock car drivers, back injuries emerged as one of the most frequently reported injuries, whereas head and neck injuries exhibited a higher likelihood of necessitating hospitalisation. Within the subset of injuries requiring hospitalisation, 12.5% were identified as concussions, contrasting with earlier literature reporting concussions rates ranging from 2-5.4% for racing injuries.

In their study, 12.5% of 40 stock car driver-athletes disclosed previous neck injuries that required hospital care, while previous reports of neck injuries requiring hospitalisation ranged from 16.0-34.0% of driver-athletes (Ebben and Suchomel, 2012).

A narrative review of the published literature revealed a relatively high rate of concussion in motorsport compared to other sports. However, interpreting concussion data in motorsport is challenging as the data varies depending on the type of vehicle, country, category of motorsport, level of competition, and driving terrain. Consequently, the data presented in the literature may not accurately represent the actual incidence and prevalence of concussion in motorsport (Deakin and Hutchinson, 2017).

The evaluation and diagnosis of concussion trackside remains challenging for medical personnel and practitioners, and making return-to-race decisions remains problematic in motorsport. Published literature illustrates that driver-athletes are at a significant risk of concussion, but the reported incidence of concussion in the literature ranges from 6.3% to 25% (Deakin and Hutchinson, 2017). In a previous survey of motorsport competitors, 45% out of 32 driver-athletes had experienced a previous concussive episode, but only half of these incidents were discussed with doctors, which raises concerns for the motorsport community (Deakin and Hutchinson, 2017). The increased incidence of concussions reported in the literature may be due to an increased awareness and diagnosis of concussions in recent years. In future, education of driver-athletes in motorsports should focus on clarifying common terms and defining concussions to encourage positive reporting behaviours for suspected concussive injuries (Bretzin, Hines and Ferguson, 2022). It is also believed that incidents of head and neck injuries in motorsport may be on the decline, potentially attributed to technological advancements and the implementation of head and neck restraining devices (Ebben and Suchomel, 2012).

Minoyama and Tsuchida (2004) conducted a retrospective study to investigate the injuries recorded during and after circuit car races held at the Fuji Speedway in Japan between 1996 and 2000. They reported that neck sprains and bruises were the most common injuries recorded in single-seater and saloon cars. The incidence of injuries acquired during single-seater car racing included 34% neck injuries, 10% head or face injuries, 14% upper limb injuries, 24% lower limb injuries, 8% chest injuries, and 8% back injuries. They did not report on the remaining 2% of injuries sustained during single-seater car racing.

The incidence of injuries acquired during saloon car racing was as follows: 53% neck injuries, 21% upper limb injuries, 16% lower limb injuries, 5% head and face injuries, 2% chest injuries, and 3% back injuries. All neck injuries reported were sprains, and there were no serious injuries.

2.4.2.2 Overuse/Chronic Injuries

In addition to acute injuries resulting from crashes and trauma, overuse and chronic musculoskeletal disorders are prevalent in motorsport. Driver-athletes often suffer from overuse musculoskeletal injuries, which can be attributed to various factors associated with the physical demands of driving. These factors include high G-forces, as well as vibrations and shocks from the vehicle (Backman *et al.*, 2005; Baur *et al.*, 2010; Ebben and Suchomel, 2012). Consequently, driver-athletes commonly experience issues such as shoulder fatigue, arm soreness, hand fatigue, and neck pain (Ferguson, 2018; Minoyama and Tsuchida, 2004).

In prior investigations, a notable prevalence of wrist injuries and back pain has been documented among rally and Formula 1 drivers (Mansfield and Marshall, 2001). Specifically, during the 1982 racing season, Raschner, Platzer and Patterson (2013) reported that 88% of Formula 1 drivers consistently encountered lower back pain. Furthermore, findings by Backman *et al.* (2005) reported that 63% of Formula 1 drivers reported wrist problems after a Grand Prix race, while 32% of rally drivers expressed discomfort in their wrists and hands. Moreover, recurrent lower back pain was reported by 88% of Formula 1 drivers, with up to 70% of all driver-athletes experiencing lower back pain at some point over their careers (Baur *et al.*, 2010). Sixty-three percent of Formula 1 drivers also experienced cervical symptoms during and after races. In rally drivers, 70% of driver-athletes reported problems in the lumbar spine, 54% reported symptoms in the cervical spine, and 47% reported musculoskeletal symptoms in their shoulders (Backman *et al.*, 2005).

Mansfield and Marshall (2001) conducted a study to investigate the incidence and severity of musculoskeletal discomfort in professional and amateur rally driver-athletes during the 2000 rally stage competition season. For their investigation, surveys were disseminated to rally clubs or administered in person during the 2000 Welsh Rally. The results indicated a significant prevalence of musculoskeletal symptoms and disorders affecting the entire body among participants in rally events. Specifically, 91% of rally driver-athletes engaging in more than 10 days of competition per year reported experiencing discomfort in at least one body area after rallying. Drivers, in comparison to co-drivers, reported a higher incidence of wrist and hand symptoms.

Pain, aching, or discomfort was most frequently reported in the lumbar spine (70%), followed by the cervical spine (54%), and shoulders (47%). Additionally, a loss of dexterity in the hands was also reported.

In a retrospective study investigating musculoskeletal injuries in more than 130 drivers, pain in the upper legs and lumbar spine were identified as some of the most common complaints (Reid, 2022). Other common complaints among driver-athletes included neck pain, shoulder fatigue, arm soreness, and hand fatigue and soreness (Ferguson, 2018; Minoyama and Tsuchida, 2004). A summary of the current motorsport-related injury research is summarised in Table 3 below.

Table 3. Current Motorsport-related Injury Research.

AUTHOR/S	TYPE OF MOTORSPORT INVESTIGATED	AIMS & METHODOLOGY	FINDINGS
Ebben and Suchomel (2012)	Stock cars	To assess the physical demands, injuries, and conditioning practices of stock car drivers. N=40	• Extreme fatigue was the most common feeling after a demanding race, with shoulder fatigue the most common. • Back and torso injuries were the most commonly reported problem, but head and neck injuries were most likely to require hospitalisation. • For those injuries requiring hospital care, 12.5% were concussion. • Of the participants, 37.5% reported no ongoing physical problems, whereas 22.5% reported ongoing back pain and another 15% suffered from neck pain. • 43% had upper extremity injuries and 17.5% had lower extremity injuries.
Hay, Singh and Hay (2023)	Motocross	To demonstrate the impact of Motocross on orthopaedic presentation and workload over five years.	• 615 orthopaedic injuries associated with recreational and competitive motocross were recorded. • The most common injuries were clavicle fractures (14%), long bone fractures (11%), forearm/distal radius fractures (9,7%) and shoulder injuries (8,9%). • Distribution of injuries – 28% hand& wrist, 24% foot and ankle, 21% spine, 27% shoulder and elbow. • Young males were identified as the highest risk participant.
Kilper *et al.* (2021)	Motocross	To evaluate the accidents and possible injuries in a single Supercross competition. N=93	• Five participants had to be admitted to the hospital (Injury rate 4.65%). • Participant 1: 9-year-old driver suffered a blunt abdominal trauma. • Participant 2: 29-year-old driver suffered a compression lesion of anterior column of T4 & t5, non-displaced fracture of left transverse process of T3. • Participant 3: 32-year-old driver who sustained facial skull contusion, teeth damage, laceration of tongue, upper lip and vestibule, thoracic contusion. • Participant 4:33-year-old driver who presented with clavicle fracture and burst fracture of L2. • Participant 5: 22-year-old driver suffered fractures of metatarsal bones II and IV.

Table 3 continued.

AUTHOR/S	TYPE OF MOTORSPORT INVESTIGATED	AIMS & METHODOLOGY	FINDINGS
Mansfield and Marshall (2001)	Rally racing	To investigate by a questionnaire the prevalence of symptoms of musculoskeletal injuries after rallying in professional and amateur stage rally competitors. Professional rally competitors N=12 Amateur rally competitors N=105	• 91% (n=90) of competitors who competed for more than 10 days a year reported discomfort in at least one body area after rallying. • Problems in the lumbar spine (70%), cervical spine (54%), shoulders (47%) and thoracic spine (36%) were the most common. • There was a higher prevalence of cervical spine discomfort for co-drivers (60%) and a higher prevalence of discomfort in the hand and wrists (32%) for drivers.
Minoyama and Tsuchida (2004)	Circuit car racing	To report injuries recorded during and after races between 2996 and 2006 at Fuji Speedway, Japan. Single-seat cars N=1020 Saloon cars N=1577	• 50 injuries were recorded during single seat races (Injury rate 1.2 per 1000 competitors per race). • 62 injuries were recorded during saloon car races (0.9 per 1000 competitors per race). • 13 injuries were recorded after the race, 12 of them in saloon car racing. • Bruises were the majority injury in single seat car racing (58%) with lower limb bruising more common than upper limb bruising. • Most injuries in saloon car racing were neck sprains (53.2%). • The incidence of concussion was high in both groups.

Table 3 continued.

AUTHOR/S	TYPE OF MOTORSPORT INVESTIGATED	AIMS & METHODOLOGY	FINDINGS
Sabeti-Aschraf *et al.* (2008)	Enduro Motorcycling	Prospective investigation to record the predominantly overused body regions and then establish the specific overuse syndrome. The study was planned in two stages (stage 1 being the feasibility study) Phase 1: N=170 Phase 2: N=128	• Hands/wrist and forearm were the most painful regions of the body. • Most riders who had symptoms at the wrist and forearm also had paresthetic sensations in the hand. • After second phase, 51.76% of all riders had pain in their forearms. • A transient Carpal Tunnel Syndrome in the wrist were seen in more than 50% of endure motorcyclists. • Enduro motorcycling has a very high potential to cause overuse syndromes. The hands and forearms are much more frequently affected than any other body region.
Tomida *et al.* (2005)	Motorcycle racing	To investigate the incidence and pattern of injuries, relative risks, and factors affecting incidence among elite motorcycle competitors in Japan. Total N=117 Road racing N=36 Motocross N=60 Trial bike riders N =21	• Sixty major injuries were reported (25 in road racing, 32 in motocross and 3 in trial bike riding). • Most common injuries were fractures (n=45), ligament injuries (n=8), dislocations (n=5) and soft tissue injuries (n=2). • Overall injury rate 22.4 per 1000 hours. • No significant correlation between risk of injury and age, experience or accumulated competition points.

Table 3 continued.

AUTHOR/S	TYPE OF MOTORSPORT INVESTIGATED	AIMS & METHODOLOGY	FINDINGS
Wertman, Gaston and Heisel (2016)	NASCAR drivers	A descriptive epidemiological study to investigate position-specific upper extremity injuries in NASCAR drivers and pit crew members. N=226 team members treated between July 2003 and October 2014	• 118 injuries (52%) occurred during racing events or practices. • Majority of injuries occurred in pit crew members, with 16% injuries in drivers. • Car crashes resulted in 32% of injuries sustained in drivers. • Neuropathies occurred in 26% of driver's injuries, including carpal/cubital tunnel syndrome and digital neuromas. • The most commonly encountered injuries in NASCAR drivers were upper extremity fractures (32%), primarily distal radius and scaphoid fractures.
Zasa *et al.* (2016)	MotoGP motorcycle road racing	The study investigated the incidence, pattern, relative risk and external factors affecting injuries recorded by the medical team during the 2014 MotoGP season. N= 101 elite motorcycle competitors	• 191 injuries were recorded. • 28 (14.6%) were major injuries. • The most common major injuries were fractures (9.9%), followed by joint dislocations. • Musculoskeletal injuries represented 88,43% of acute injuries. • Concussions were diagnosed in only 1.57%. • The most common orthopaedic injuries were upper extremity contusion and the most common anatomical area for fractures was the hand. • The most common affected joint by dislocation was the AC joint. • Overall injury rate was 4.14 per 1000 practice kilometres and 3.8 per 1000 race kilometres. • 149 (78%) injuries occurred during practice.

2.5 Risk Factors for Injury in Driver-athletes

Injuries in sport results arise from the interplay of various risk factors and events. These factors can be classified into modifiable and non-modifiable categories. Risk factors for sports injuries encompass aspects related to exposure, training, the environment, and equipment (Parkkari, Kujala and Kannus, 2001). Currently, there is limited published literature reporting on the specific risk factors for injuries in motorsport.

2.5.1 Non-modifiable Risk Factors

In motorsport, non-modifiable factors can include car-related factors and specific sport-related factors. Specific risk factors in motorsport includes the length of the season, the number of competitions in a season, and the level of competition (Reid and Lightfoot, 2019). Sport-specific environmental risk factors in motorsport, such as high temperatures combined with carbon monoxide, impose unique physiological demands on driver-athletes (Owen, King and Lamb, 2015). Additional environmental risk factors involve the nature of the racing surface, weather conditions, and the time of the season.

Zasa *et al.* (2016) conducted a study to investigate the impact of competition intensity on injury incidence and severity. This was achieved by comparing injury rates between practice sessions and actual races in the context of motorcycle racing. They reported that injury rates in professional road racing were higher during practices compared to races. This phenomenon is hypothesised to result from driver-athletes riding more aggressively during practice rounds to improve their starting positions and gaining a better understanding of their vehicle's limitations before the race (Zasa *et al.*, 2016). The incidence of musculoskeletal disorders among driver-athletes can also be attributed to car-specific factors such as suboptimal sitting posture in the car and the exposure to vibrations and mechanical shocks transmitted from the vehicle (Mansfield and Marshall, 2001). Non-modifiable risk factors related to the physical characteristics of driver-athletes include age and previous injuries (Parkkari, Kujala and Kannus, 2001).

2.5.2 Modifiable Risk Factors

It has been demonstrated that there is a positive correlation between body mass index (BMI) and driver weight with the likelihood of injuries in motorsport (Seiffert, Szymski and Krutsch, 2020). The experience of the driver, skill level, and training are considered positive contributors to injury avoidance (Baur *et al.*, 2006). It was previously suggested that driver-athletes with less experience are at a higher risk of being involved in accidents and sustaining injuries.

Zasa *et al.* (2016) reported a strong correlation between injury rates and professional driving experience. Furthermore, the presence or absence of protective equipment and safety clothing can expose driver-athletes to injuries (Ferguson, 2018).

Physical fitness and sport-specific skills constitute the most significant modifiable risk factors for preventing injuries in motorsport. Additionally, psychological factors such as motivation, risk-taking behaviour, and stress coping can also play substantial roles in injury risk (Parkkari, Kujala and Kannus, 2001). To develop an effective injury prevention strategy, it is essential to enhance modifiable risk factors such as the physical fitness and strength of driver-athletes, with the aim of minimising the stress placed on their bodies (Seiffert, Szymski and Krutsch, 2020).

2.6 Injury Prevention in Motorsport

Injury prevention research plays a crucial role in motorsport to mitigate the potential impact of injuries on driver-athletes. As driver-athletes may begin competing as early as 10 years old, it is essential to initiate injury prevention strategies and education at an early age (Seiffert, Szymski and Krutsch, 2020).

Physical fitness plays a crucial role in preventing musculoskeletal injuries in driver-athletes, while also enhancing their performance (Hoyes and Collins, 2018). Higher fitness levels have also been reported to speed up recovery time after injury (McKnight *et al.*, 2019; Minoyama and Tsuchida, 2004). Musculoskeletal injuries resulting from G-forces, vibrations, and shocks from the car may be reduced through musculoskeletal fitness (Backman *et al.*, 2005). Good cardiovascular fitness can minimise stress on the body caused by heat and increased heart rates (Seiffert, Szymski and Krutsch, 2020), and increased aerobic fitness has been demonstrated to reduce circulatory, cardiological, and metabolic responses to the physiological and physical demands experienced in motorsport (Baur *et al.*, 2006). To mitigate the effects of heat and increased body temperatures, driver-athletes can employ acclimatisation programmes and cooling technologies (Reid, 2022).

While some acute injuries, such as lacerations, may be challenging to prevent, other injuries such as strains, sprains, neck, and back injuries can be reduced through specific strength and conditioning programmes (Ebben, 2010). Core stability is thought to be important in preventing injuries caused by chronic exposure to vibrations such as back pain (Hoyes and Collins, 2018). Coordination, sensorimotor skills, high reaction speeds, and adequate neuromuscular control are also essential in driver-athletes to prevent direct trauma and musculoskeletal injuries (Baur *et al.*, 2006).

The incidence of severe traumatic brain injuries and concussions have decreased in recent years due to advances in protective equipment and technology (Deakin *et al.*, 2017). However, the evidence suggests that increased neck strength may also contribute to the prevention of sports-related concussions (McKnight *et al.*, 2019). Increasing isometric neck strength has been shown to decreased the deceleration velocities of the head in the event of a crash, potentially mitigating or reducing the severity of concussions (McKnight *et al.*, 2019). Accurate knowledge regarding concussions in motorsport is lacking, and concussion education and training for all driver-athletes and personnel in motorsport may aid in the prevention of concussions (Seiffert, Szymski and Krutsch, 2020).

Driver-athletes are exposed to motor vehicle crashes. Other injury prevention strategies to reduce crash injuries include the introduction of Steel and Foam Energy Reduction (SAFER) barriers at race courses, the compulsory use of head and neck restraints, and advancements in driver restraints in cars (Patalak *et al.*, 2020). To reduce the potential impact of accidents and repetitive gravitational loading, drivers wear protective clothing such as helmets, and employing safety equipment like the Head and Neck Support (HANS) device serves to further diminish the occurrence of severe injuries (Seiffert, Szymski and Krutsch, 2020; Baur *et al.*, 2006). Monitoring and enhancing the safety standards of equipment and racetracks are crucial in protecting driver-athletes from serious injuries (Seiffert, Szymski and Krutsch, 2020).

2.7 Physical Testing in Motorsport Driver-athletes

Physical fitness is important in preventing musculoskeletal injuries in motorsport (Hoyes and Collins, 2018). Physical testing in motorsport has not been investigated specifically. When reviewing the literature, a few articles were retrieved that used a battery of tests to investigate components of neuromuscular performance in motorsport (Table 4). These components were compared between driver-athletes and non-driving physically active controls (Baur *et al.*, 2006), between elite and amateur driver-athletes, and between different racing categories and series of racing (McKnight *et al.*, 2019).

Anthropometric measurements were conducted in all five of the reviewed studies, but only Backman *et al.* (2005) measured body fat percentage by measuring skinfolds and did not use the BMI as a measurement. Reaction time and multiple reaction was measured by Backman *et al.* (2005), Baur *et al.* (2006), and Raschner, Platzer and Patterson (2013) using specialised reaction time equipment. Isometric grip strength was measured by Backman *et al.* (2005) and Raschner, Platzer and Patterson (2013) using a hand-held dynamometer.

Other components that were considered important and investigated through various tests included lower limb strength, trunk flexion and extension strength, postural stability, upper limb strength and endurance, and neck strength.

Table 4. Summary of the Literature that Included Neuromuscular Testing.

AUTHOR	PURPOSE OF THE STUDY	PARTICIPANTS	COMPONENTS INVESTIGATED	TESTS
Backman *et al.* (2005)	To investigate neuromuscular performance characteristics in open-wheel and rally drivers	N = 28 - International level open-wheel drivers (n=9) - International level rally drivers (n=9) - Physically active nondriving male (n=10)	Anthropometric Measurements	Body fat percentage by measuring skinfolds Height Body mass
			Reaction Time	Choice Reaction Time
			Explosive Force Production of the Lower Limbs	Vertical Jump
			Maximal Bilat Isometric Leg Extension Force	Measured by an electromechanical dynamometer
			Isometric Grip Strength	Handheld Dynamometer
			Isometric Trunk Flexion and Extension Strength	Measured by a trunk dynamometer
			Speed and Coordination of the Lower Limbs	Foot-Step Test
			Jumping Power	Maximal fast take-offs on a contact mat (New Test)
			Maximal Isometric Plantar Flexion Force	Measured by an electromechanical dynamometer
			Shoulder Strength	Maximal Isometric Shoulder Extension using a bar with a force sensor Maximal Isometric Shoulder Flexion using a bar with a force sensor
			Shoulder Endurance	Isometric Shoulder Extensor Endurance Test
			Neck Strength	Isometric Neck Strength Test using the neck strength measurement system (NSMS)

Table 4 continued.

AUTHOR	PURPOSE OF THE STUDY	PARTICIPANTS	COMPONENTS INVESTIGATED	TESTS
Baur *et al.* (2006)	To compare reaction time, stability, performance capacity and strength performance capacity of elite racing drivers with those of age-matched, physically active controls	N = 18 - Racing drivers (n=8) - Age-matched physically active controls (n=10)	Anthropometric Measurements	Body mass Height BMI
			Reaction Time	"Go/no go" condition on the Vienna Reaction Apparatus
			Stability	Postural stability tested on a two-dimensional free moving platform
			Strength Performance Capacity	CON-TREX LP linear leg press CON-TREX MJ multi-joint system with an adapted steering device for upper extremity testing
			Strength Endurance Capacity	CON-TREX MJ multi-joint system in a seated position
Baur *et al.* (2010)	To compare maximal trunk extensor and flexor strength of elite race car drivers and physically active controls	N=26 - Elite race car drivers (n=13) - Male controls who engage in recreational sport activities (n=13)	Anthropometric Measurements	Body mass Height BMI
			Maximal trunk extensor and flexor strength	CON-TREX TP isokinetic device for trunk flexion and extension
McKnight *et al.* (2019)	To compare the physical fitness variables of elite-level race car drivers across various competitive championships	N=18 - Formula 1 drivers (n=5) - IndyCar drivers (n=5) - IMSA GTD drivers (n=4) - NASCAR drivers (n=4)	Anthropometric Measurement	Body mass Height Dual energy x-ray absorptiometry
			Peak Oxygen Uptake	VO2peak treadmill test
			Isometric Neck Strength	Gatherer System Device or Iron Neck head harness

Table 4 continued.

AUTHOR	PURPOSE OF THE STUDY	PARTICIPANTS	COMPONENTS INVESTIGATED	TESTS
Raschner, Platzer and Patterson (2013)	To compare selected fitness parameter of experienced and junior open-wheel race car drivers	N=18 - Formula 1 drivers (n=5) - GP2 drivers (n=2) - Formula 3 drivers (n=2) - Junior drivers competing in Formula Master, Koenig, BMW and Renault series (n=9)	Anthropometric Measurement	Boy Weight Height BMI
			Multiple Reactions	Multiple reaction test using a reaction board
			Multiple Anticipation	Multiple anticipation test using an anticipation test device
			Postural Stability	One-legged sensorimotor test using the Biodex Stability System (BSS)
			Isometric Upper Body Strength	Isometric core flexion and extension using the Back-Check
				Isometric bench press and pull tests using the MLD-Station Evo2
			Isometric Leg Extension Strength	Seated unilateral leg press using a load cell under the foot plate
			Isometric Grip Strength	Hand grip dynamometer
			Cyclic Foot Speed	Cyclic foot speed using a force plate
			Jump Height	Counter-movement jump

Williams (2021) conducted a literature review to offer insights into current trends in testing and training protocols within the motorsport community. They reported on a fitness-testing battery created to assess the physiological capacity of driver-athletes (Williams, 2021). As this specific testing protocol requires specialised equipment and expertise, they proposed a field-based testing battery (Table 5) that can be implemented to complement laboratory tests (Williams, 2021).

Table 5. Recommended Field-based Testing Battery for Open-wheeled Racing Drivers (adapted from Williams, 2021).

COMPONENT	TESTS	HOW TO CONDUCT
Anthropometry	Height, Weight, and Skinfold	Measuring Tape, Digital Scale, and Skinfold Callipers
Cardiovascular Fitness	Yo-Yo Intermittent Recovery Test Level 1 (YYIR1)	YYIR Cone Setup: 20m with 5m recovery section. Prediction calculation to estimate VO2max = IR1 distance (m) x 0.0084 + 36.4
Anaerobic Threshold	Running-Based Anaerobic Sprint Test (RAST)	8 x 35m sprints, with 20s recovery between each repetition. Measure lactate concentration after each repetition using a Portable Lactate Analyser
Lower Body Anaerobic Power	Vertical Jump	Measure distance (cm) between standing reach and maximum jumping reach on a flat wall. Allow for 3 repetitions
On-Track Physiological Response	Heart rate + RPE	Get the athlete to drive around a road-course track in an open-wheeled vehicle for a set amount of time and measure heart rate using a smart watch

The majority of tests used in the literature to examine the components of neuromuscular performance in motorsport require expensive equipment, making them not always reproducible. There is a need for more field-based tests that are inexpensive and easily reproducible, particularly for studies that lack the resources or funding for specialised equipment. Testing procedures that closely mimic actual racing and driving conditions are also essential for a successful transfer to competition (Baur *et al.*, 2006).

2.8 Summary of the Literature

The environment of motorsport is unique, and there are many physiological and physical challenges that driver-athletes face. Some of these challenges include increased heart rates and cardiovascular demand, repetitive gravitational loading, heat stress, shocks and vibrations from the car, increased metabolic demand, carbon monoxide exposure, and muscular stresses related to the physicality of driving and steering the car (Backman *et al.*, 2005; Minoyama and Tsuchida, 2004; Seiffert, Szymski and Krutsch, 2020). These repeated challenges of motorsport can induce negative outcomes such as dehydration, fatigue, loss of performance, mental errors, and an increased risk of accidents and injuries (Reid, 2022; Matthews and Pike, 2016). Injuries in motorsport have not been widely researched. Due to the different categories and vehicle designs, it is difficult to generalise motorsports as one category when investigating injuries (Minoyama and Tsuchida, 2004; Seiffert, Szymski and Krutsch, 2020).

Compared to disciplines such as motocross and motorcycle racing, there is a lower incidence of injuries in four-wheeled motorsports (Seiffert, Szymski and Krutsch, 2020). In addition to acute injuries resulting from crashes and trauma, overuse and chronic musculoskeletal injuries are also prevalent in motorsport. Research on injury prevention is a crucial aspect of motorsport to reduce the possible injury risk for driver-athletes. Physical fitness plays a key role in preventing musculoskeletal injuries in driver-athletes and helps enhance their performance (McKnight *et al.*, 2019). A well-designed strength and conditioning programme has also been shown to prevent and reduce the severity of neck injuries and sports-related concussions (McKnight *et al.*, 2019).

Physical testing is essential for formulating appropriate training programmes and devising strategies for injury prevention within the field of motorsport. However, physical testing in motorsport has not been widely investigated. Most tests used in the literature to assess components of neuromuscular performance require expensive equipment, making them less reproducible. Inexpensive and reproducible field-based tests are needed for future studies in motorsport that lack the resources or funding for specialised equipment.

Given the lack of existing literature on injuries in motorsport and the training and fitness regimens of driver-athletes in the context of South Africa, the present study was designed to investigate demographic data, training history, injury history, and evaluate fitness parameters in driver-athletes in South Africa, as elaborated in the following chapter.

CHAPTER THREE: METHODOLOGY

3.1 Research Problem

Driver-athletes are exposed to various physical and physiological demands, rendering them susceptible to both acute and overuse injuries (Backman *et al.*, 2005). Despite the increasing popularity of the sport, there is a lack of scientific literature addressing the physical and physiological demands inherent to motorsport, and the injuries sustained in motorsport have not been widely researched (Raschner, Platzer and Patterson, 2013; Minoyama and Tsuchida, 2004).

The research problem addressed in this dissertation is the lack of scientific literature on the physical and physiological demands, injuries, and injury prevention in motorsport. It also directly addressed the lack of knowledge of the significance of physical fitness in presenting injuries within the realm of motorsport in South Africa. Therefore, the aim of this study was to explore and describe the fitness, injury, and training profiles of South African motorsport driver-athletes. The specific objectives have been described in Section 1.5.2 above.

3.1.1 Study Design

The original, intended study design was a descriptive cross-sectional study that investigated the demographic, fitness, and training profiles of South African motorsport driver-athletes. However, due to slow recruitment rates (discussed in Chapter Four), the study design was amended to incorporate a descriptive study that utilised a self-developed online survey to gather information on the demographic attributes, sport-specific information, training history, and injury history of driver-athletes. We then conducted a battery of physical tests to determine the upper limb strength, lower limb strength, reaction time, coordination, neck strength, and cardiovascular fitness of a small cohort of driver-athletes, and these results have been reported as a case series.

3.1.2 Inclusion Criteria

Adult (i.e., individuals 18 years or older) female and male motorsport driver-athletes competing in circuit car racing at social, club, regional, or national level were included in this study.

3.1.3 Exclusion Criteria

Driver-athletes currently suffering from a musculoskeletal disorder that prevented them from completing the physical tests as per the Nordic Musculoskeletal Questionnaire (NMQ) were excluded from this study. Any driver-athletes declared unsafe to participate in physical exercise as per the Physical Activity Readiness Questionnaire (PAR-Q+) were also excluded.

3.1.4 Sample Size

Sample size was determined using an online sample size calculator from https://sample-size.net/sample-size-means/ (accessed 19 July 2021) that compared the mean of a continuous measurement in two samples (Chow *et al.*, 2007; Hulley *et al.*, 2013). The sample size calculation was based on data derived from male and female athletes for the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST; Ellenbecker, Manske and Davies, 2000). Based on an effect size of 2, a standard deviation of 2.5, and statistical significance accepted as $p < 0.05$, a required sample size of 52, 70, and 82 participants would provide 80%, 90%, and 95% statistical power for the CKCUEST test respectively.

3.1.5 Stakeholder Engagement

Exercise and sports medicine is a term commonly used to describe any type of investigation that addresses questions related to the prevention, treatment, diagnosis, or prognosis of diseases or injuries, as well as the enhancement and maintenance of health (Bandholm *et al.*, 2018). However, it is increasingly evident that research findings in exercise and sports medicine are not widely integrated into many sporting environments. One possible explanation for this lack of adoption is that research outcomes and evidence may not be perceived as sufficiently important or directly relevant to the sport itself or its key stakeholders (Finch, 2017). Stakeholder engagement, defined as "the involvement of those affected by the outcomes of a research process" (Hendricks, 2021, p. 1), can encompass a broad spectrum of individuals including patients, athletes, coaches, target populations, policymakers, administrators, medical directors, and others (Hendricks, 2021; Finch, 2017; Bandholm *et al.*, 2018). Stakeholder engagement in research typically occurs during the recruitment and dissemination phases and therefore there is less emphasis on identifying and engaging relevant stakeholders from the initial stages of research, as well as throughout the data analysis and interpretation stages (Goodman *et al.*, 2020).

In their work, Bandholm *et al.* (2018) put forth the REAL concept, which comprises four key principles aimed at enhancing the clinical relevance of research in the field of sport and exercise medicine.

These four essential points include: 1) Relevance of the research question, 2) End-user and stakeholder identification, 3) Acknowledge and appraise end-user and stakeholder input, and 4) Look again at the research usefulness. The first step of research should be to determine the end-user of the research results. Careful consideration should then be taken to determine whether the research is relevant for end-users and to ensure that it is implemented within sporting contexts (Goodman and Sanders Thompson, 2017; Bandholm *et al.*, 2018). A common mistake to avoid is assuming that others will automatically find the research results as interesting or significant as the researchers themselves. One strategy to prevent this is to engage stakeholders in the process of formulating the research question (Bandholm *et al.*, 2018). By involving stakeholders, valuable insights into the specific research needs and requirements can be obtained within the sporting context (Finch, 2017). Just as crucial is the careful selection and measurement of outcomes that bear significance for the target population, facilitating informed decision-making concerning the research topic. The benefits of engaging stakeholders in research include the improvement of participant recruitment and retention, contribution to appropriate research questions, study designs, and methodology, and more successful implementation and communication of the research findings (Goodman *et al.*, 2020).

During the protocol development phase of the present study, we reached out to multiple stakeholders. These stakeholders included the operations manager of Motorsport South Africa (MSA), as well as their medical and insurance coordinator. Our discussions with these stakeholders revolved around the research study aims and objectives. We also delved into conversations regarding the various racing categories in South Africa and the number of driver-athletes registered within each category. This information was instrumental in shaping the research question and determining the study population. Subsequently, we sought assistance from a personal contact who is an experienced driver-athlete to gather pertinent information for the study.

As the recruitment phase commenced, we expanded our outreach to numerous other stakeholders and key figures within the motorsport community in the Western Cape. This extended list of contacts included driver-athletes, the owner of one of Killarney International Raceway's major sponsorships, the chairman of the Sports and GT Racing Group, the director of a driver training company, a live talk show host and commentator at Killarney International Raceway, and a Motorsport journalist, among others. While some of these stakeholders actively participated in assisting with recruitment, others we contacted displayed no interest in the research or were unwilling to offer their assistance in any way.

3.1.6 Recruitment

Motorsport South Africa and Killarney International Raceway were approached for permission to recruit participants through their media sites and to share the recruitment advertisement online (Appendix A). Relevant motorsport clubs received communication through email and were requested to circulate the advertisement to their members (Appendix B). The recruitment advertisement was published in the May 2023 circular of Killarney International Raceway, and this was also sent electronically to driver-athletes on their mailing list. Furthermore, important stakeholders within the motorsport community were approached and contacted individually to assist with recruitment. An interview on an online talk show was conducted where a background of the study's purpose and the aims of the study were presented.

Further efforts were made by attending a race day at Killarney International Raceway to personally engage with driver-athletes and stakeholders. After receiving a list of contact details, driver-athletes were contacted via email or telephonically and the recruitment advertisement was shared with them. Participants were recruited from the Western Cape and more specifically, areas surrounding Killarney International Raceway and the Western Province Rugby High Performance Centre, to reduce travelling distances to the testing site. Follow-up attempts to recruit participants to complete the online survey were made by sending a link to the online survey via email or WhatsApp to all stakeholders and driver-athletes previously approached, and the link was also shared by drivers on their respective motorsport WhatsApp groups.

3.2 Ethical Considerations

Ethical approval was obtained from the HREC in the Faculty of Health Sciences at the University of Cape Town (HREC-REF: 092/2023; see Appendix C) and the study followed the ethical principles set out in the Declaration of Helsinki (World Medical Association, 2013). Participants completed an informed consent form, which outlined the study aims and procedures, before any data collection took place. The document emphasised participants' right to withdraw from the study at any point, while also providing a clear overview of the associated risks and benefits (Appendix D).

Participant data were encoded, ensuring that no personal identifying information was included in the data spreadsheet. Confidentiality of participant data was ensured as no personal identifiers was used when reporting the outcomes of the study. The execution of physical tests posed a potential musculoskeletal injury risk, yet this risk was mitigated through adequate warm-up measures and comprehensive explanations of the testing procedures.

Participants in the study did not receive direct individual benefits; however, they were provided with feedback regarding their test results. The feedback may assist participants in identifying areas where they could improve performance and possibly prevent injuries.

3.3 Measurement Instruments

3.3.1 Informed Consent

The informed consent document delineated the study's aims, objectives, testing procedures, and the corresponding risks and benefits. Participants were apprised of their choice to withdraw from the study at any point. The informed consent form also detailed the confidentiality measures which were put in place to ensure participant's privacy. Before undergoing physical testing, participants were required to complete an informed consent document prior to the initiation of the testing procedures. The first section of the online survey comprised of the informed consent from. Where informed consent was not provided, the potential participant was exited from the survey.

3.3.2 Nordic Musculoskeletal Questionnaire (NMQ)

The NMQ was used to exclude driver-athletes who suffered from any musculoskeletal disorders that may have prevented them from completing the physical tests. The test-retest reliability of the NMQ has been determined as good (Chairani, 2020). The NMQ is a useful and sensitive screening tool for musculoskeletal disorders (Crawford, 2007) and has been included in Appendix E. Participants were asked about any musculoskeletal problems experienced over the past 12 months and the previous seven days which prevented them from completing normal activities of daily living (Crawford, 2007).

3.3.3 Physical Activity Readiness Questionnaire (PAR-Q+)

The PAR-Q+ is a self-screening tool used by individuals to determine whether it is safe to be part of an exercise programme and has been included in Appendix F (Warburton *et al.*, 2021). Individuals identified as unsuitable for engaging in physical exercise, as determined by the PAR-Q+, were excluded from the study and recommended to seek medical advice. The validity and reliability of the PAR-Q+ have been previously established (Warburton *et al.*, 2011).

3.3.4 Demographic, Training History, and Injury Questionnaire

A self-developed questionnaire was used to assess demographic characteristics, sport-specific information, training history, and the injury history of driver-athletes (Appendix G). The questionnaire was developed as an online survey via Google Forms and a link to the survey was shared with participants.

The first section of the survey compromised of the informed consent form (Appendix D), that included information about the study aims and procedures. Where informed consent was not provided, the potential participant was exited from the survey. The type of questions and answering options varied and included: single yes/no, short answers, multiple choice, single choice drop-down menus, checkboxes, and a seven-point Likert scale.

A panel consisting of three experts in sports medicine and physiotherapy assessed the survey to ascertain content and construct validity. The panel included an academic exercise physiologist with a special interest in motorsport, and two physiotherapists with respective PhD and MSc qualifications in sports physiotherapy and exercise medicine. Based on the feedback received from the expert panel, several changes to the survey layout were made. Drop-down boxes were incorporated to enhance user-friendliness. Additionally, Likert scale questions for assessing sleep quality were introduced, and epilepsy was included as a response option for the health-related question. In order to provide clarity, "current" and "past" injuries were defined within the survey, and a specific time frame for reporting injuries was also established. A pilot study was then conducted to assess the feasibility of the survey. The survey was sent to two driver-athletes, and the feedback received was used to make appropriate changes. Questions were incorporated into the survey to assess an aspect of performance. These questions included inquiries about the class the participants drove in, what type of vehicle they drove, and whether or not they were sponsored.

3.3.5 Anthropometry

A calibrated scale (Masskot Mass Measuring Scale Model Mi-301) was used to measure body mass (kg) and stature (cm) was measured using a stadiometer (HM-250P Leicester Height Measure). Body fat was expressed as a percentage and as the sum of seven skin folds (chest, mid-axilla, triceps, subscapula, abdomen, suprailium, and thigh; Marfell-Jones, 1991). Skin folds were measured by an experienced and accredited biokineticist using a calliper, with measurements taken on the right side of the body (Marfell-Jones, 1991). Three measurements were taken for each of the seven skinfolds, and the average was used for analysis. The midabdominal waist circumference was measured at the midpoint between the lowest ribs and the iliac crest utilising a tape measure, as per the methodology outlined by Ma *et al.* (2013). Body mass index was calculated using the formula: $\frac{Mass\ (kg)}{Height\ (m)^2}$.

3.3.6 Warm-up

It was required of participants to perform a warm-up protocol that included a cardiovascular and lower limb warm up on a stationary bike, and a dynamic warm-up routine for the upper body. They cycled for five minutes at an intensity of 13 on the Borg scale (Borg, 1982), which has been included in Appendix H. The Borg scale was displayed to the participants before and during the warm-up protocol. Thereafter, participants completed a dynamic warm-up routine for the upper body that included 10 repetitions of each of the following exercises: neck flexion/extension, neck side flexion, cross-body arm swings, side-to-side arm swings, diagonal arm swings, large arm circles, spinal rotations, and wrist circles.

3.3.7 Single-leg Heel Raise Test

The purpose of the single-leg heel raise test (Figure 2) was to assess the muscle endurance of the ankle plantar flexors. One leg was tested at a time and the alternate limb was tested after a two-minute rest (Hébert-Losier *et al.*, 2017). Without shoes, the participants stood on an 10˚ incline board in slight dorsiflexion, supporting with their fingertips at shoulder height on a wall in front of them (Hébert-Losier *et al.*, 2017). The participants were then instructed to rise onto the ball of the foot as high as they could while keeping the trunk and knee straight. The participants continued until they were unable to rise through the full range of motion or voluntarily stopped due to fatigue. The heel raise was performed at one cycle per second (Dennis *et al.*, 2008a). The participant was scored using the number of heel raises completed for each side. The intra-tester and inter-tester reliability for this test has previously been established as excellent (Dennis *et al.*, 2008a; Dennis *et al.*, 2008b).

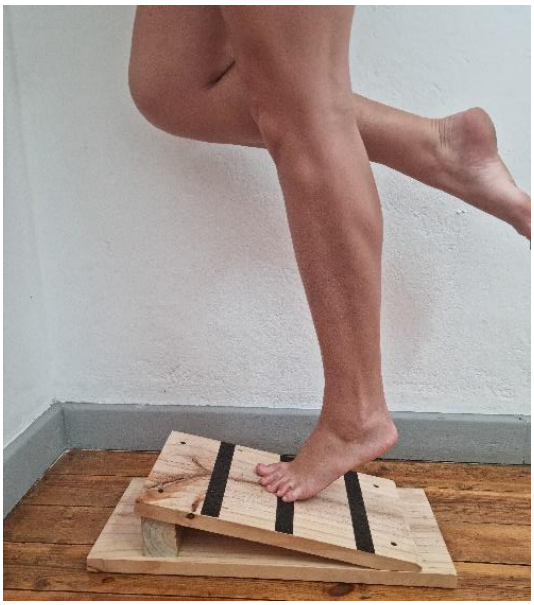

Figure 2. Single-leg Heel Raise Test.

3.3.8 Wall Toss Test

The wall toss test (Figure 3), as described by Ashok (2008), was employed to assess hand-eye coordination. Participants stood behind a designated 2-meter mark facing the wall, holding a tennis ball in the right hand, with knees slightly bent and feet shoulder-width apart (Du Toit *et al.*, 2010). Participants were directed to execute underarm throws of the tennis ball from the right hand against the wall, aiming to catch the ball with the left hand (Ashok, 2008). Subsequently, the process was reversed, involving throws with the left hand and catches with the right hand. This cycle was repeated for a duration of 30 seconds, and the number of successful catches was recorded (Du Toit *et al.*, 2010). The validity and reliability for the wall toss test has previously been established (Faber, Oosterveld and Nijhuis-Van der Sanden, 2014).

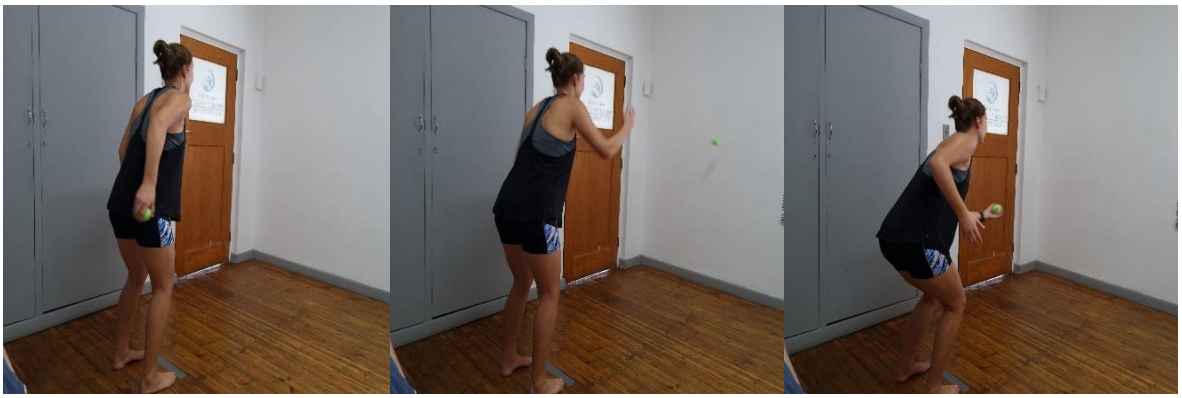

Figure 3. Wall Toss Test.

3.3.9 Grip Strength

A Saehan Hydraulic Hand Dynamometer (Model SH5001) was used to measure grip strength (Figure 4). Participants, following the recommendation of Trampisch *et al.* (2012), gripped the dynamometer with the handle set at position two (4.8 cm). In a seated position with a 90 ° bend in the elbow and the forearm in a neutral position, participants were instructed to exert maximal pressure on the handle for a three-second duration, followed by complete relaxation of the hand. This was repeated two more times with 15 seconds rest between each test (Trampisch *et al.*, 2012). The test was then be repeated on the other side. Handedness was assessed by asking, “which hand do you use to cut with scissors or cut bread with a knife” (Trampisch *et al.*, 2012, p. 2369). Validity and reliability for using a hydraulic hand dynamometer to measure grip strength have previously been established (Mathiowetz *et al.*, 1984).

Figure 4. Grip Strength.

3.3.10 Foot Step Test

The foot step test (Figure 5), developed by Backman *et al.* (2005), was used to measure coordination and speed of the lower limb in open-wheel and rally driver-athletes. Two marks, positioned 30 cm apart on the floor, served as reference points. Participants, maintaining an upright seated position with a 90˚ knee flexion, were directed to rapidly move their foot back and forth over the marks for a duration of 15 seconds (Backman *et al.*, 2005). The test was conducted twice for each leg, interspersed with a 15-second rest between trials. The average performance for each leg was then calculated and utilised for data analysis. The validity and reliability of this test had not been previously established. It was decided to include this test in the battery of physical tests because it is the only test for lower limb coordination and speed conducted among motorsport driver-athletes to date, and no other field-based tests for lower limb coordination in healthy adults could be found.

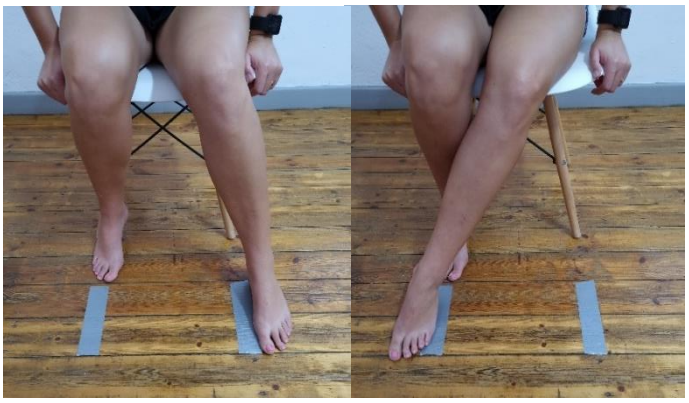

Figure 5. Foot Step Test.

3.3.11 Neck Flexor Endurance Test

The neck flexor endurance test (Figure 6) was employed to evaluate the endurance of the deep neck flexor muscles. Participants assumed a supine, crook-lying position with hands resting on their stomach (Domenech *et al.*, 2011). The participant was then instructed to “tuck the chin” completely and to maintain this position. In this position, participants were instructed to fully "tuck the chin" and maintain that posture. A line was drawn across two closely approximated skin folds along the participant's neck. The investigator then positioned their left hand on the table just below the occipital bone of the participant's head. Participants were directed to lift the head and neck approximately 2.5 cm while keeping the chin retracted to the chest. The test concluded if the edges of the lines no longer approximated each other due to loss of chin tuck or if the participant's head touched the investigator's hand for more than one second (Domenech *et al.*, 2011). The participant was allowed one deviation from the testing position and verbal cues were given to correct the position. The time that the participant could hold the test position was measured. The testing procedure was repeated twice with two-minute rests between each procedure. The average of the two testing procedures was used for analysis. Inter-tester reliability for this test has been determined as moderate to good, and intra-tester reliability was established as good to excellent (Selistre, de Sousa Melo and de Noronha, 2020).

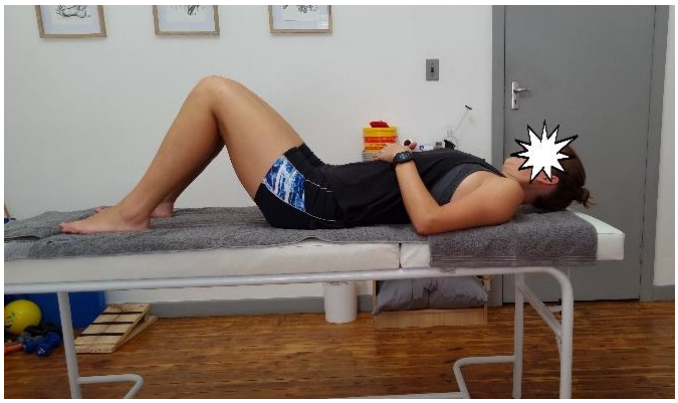

Figure 6. Neck Flexor Endurance Test.

3.3.12 Ruler Drop Test

The ruler drop test (Figure 7) was used to assess reaction and movement time (Del Rossi, Malaguti and Del Rossi, 2014). Seated on a chair, the participant maintained a 90 ° flexion in the elbow, with the forearm in mid-pronation and supported on the table, aligning the open hand at the edge of the surface, as specified by Ángel Latorre-Roman *et al.* (2018). The investigator suspended a 30 cm metal ruler vertically, positioning the 0 cm mark to coincide with the borders of the thumb and index finger (Ángel Latorre-Roman *et al.*, 2018).

The index finger and thumb of the participant's hand was aligned with 5 cm between the fingers to standardise the test (Anitha and Samuel, 2018). The participant was instructed to catch the ruler as soon as possible once it was dropped. The distance at which the participant grabbed the ruler was recorded in centimetres, by measuring from the end of the ruler to the superior aspect of the participant's index finger and thumb (Anitha and Samuel, 2018). The distance measured in centimetres was then converted to reaction time in milliseconds using a mathematical formula ($t = \sqrt{d}(490\ cm/s^2)$, where t = time and d = distance*)* as described by Anitha and Samuel (2018). The testing procedure was repeated three times on both sides and the mean for each side was used for analysis. The ruler drop test has acceptable reliability and validity (Ángel Latorre-Roman *et al.*, 2018).

Figure 7. Ruler Drop Test.

3.3.13 Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST)

The CKCUEST (Figure 8) was used to evaluate the function and stability of the upper limb within a closed kinetic chain (Tucci *et al.*, 2014). To establish the initial hand placement, two parallel lines were marked on the floor, each 91.44 cm apart. The test was executed from a push-up position, maintaining a flat and parallel back to the floor, with the hands positioned 91.44 cm apart on the marked lines. Participants, using one hand, reached across to touch the opposite line and then returned to the starting position. This sequence was then repeated with the other hand. The test was conducted once, and the number of touches performed by participants in 15 seconds was recorded. The CKCUEST demonstrated excellent inter-tester and intra-tester reliability values (Tucci *et al.*, 2014).

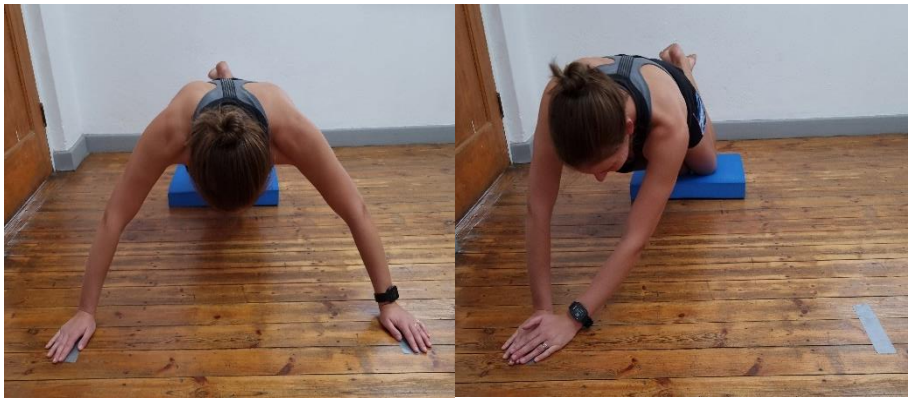

Figure 8. Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST).

3.3.14 Multistage 20m Shuttle Run Test

The 20m shuttle run test (Figure 9) was employed to assess cardiovascular fitness. This test involved continuous, incremental speed running conducted in one-minute stages (Mayorga-Vega, Aguilar-Soto and Viciana, 2015). The starting speed was set at 8.5 km.h^{-1} and increased by 0.5 km.h^{-1} per minute (Leger *et al.*, 1988). Participants ran between two lines spaced 20 meters apart, synchronising their pace with audio signals from a pre-recorded audio source (Mayorga-Vega, Aguilar-Soto and Viciana, 2015). The test concluded when the participant could no longer maintain the required pace. The recorded stage number from the final announcement was used to predict maximal oxygen uptake (Vo_2 max) based on the speed corresponding to that stage (Leger *et al.*, 1988). The validity and reliability of the 20m shuttle run test has been previously established (Aandstad *et al.*, 2011; Leger *et al.*, 1988).

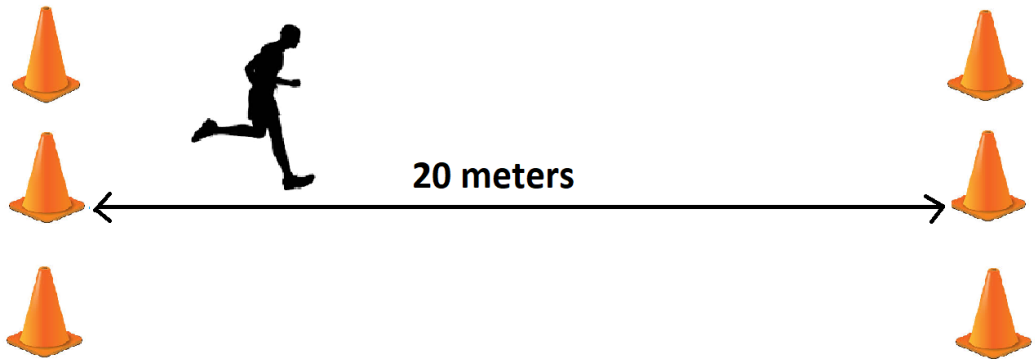

Figure 9. Multistage 20m Shuttle Run Test.

3.4 Procedure

The study protocol underwent submission to the Human Research Ethics Committee (HREC) within the Faculty of Health Sciences at the University of Cape Town to seek ethical approval. Following the approval process, stakeholders were contacted to explore options for recruiting participants.

Validity of the survey content and construct was established through an expert panel review process, while a pilot study was undertaken to assess the feasibility and reliability of the physical testing procedures. Study recruitment then commenced, and data collection was initiated simultaneously.

Once informed consent was provided, participants completed the PAR-Q+ and NMQ to screen for any exclusion criteria. Testing took place at the Western Province Rugby High Performance Centre. On the day of testing, participants received a link to the online survey to complete before the testing commenced. Anthropometric measurements were recorded, and the testing procedures were explained to the participants. Thereafter, participants were provided with an opportunity to ask any questions related to the testing procedure. Following the warm-up protocol, participants were given an opportunity to practice the tests as part of familiarisation with testing procedures, and the physical tests were then completed in a standard order of testing (Figure 10).

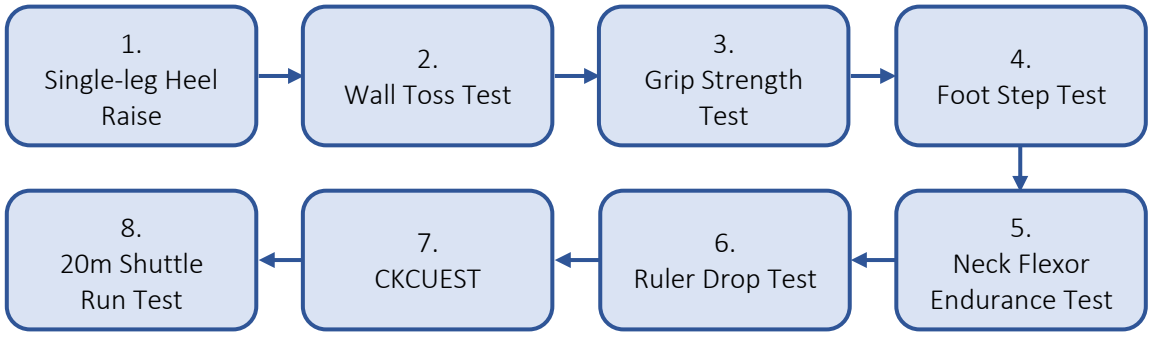

Figure 10. Order of the Physical Tests.

The recruitment phase continued for three months, and despite all recruitment efforts there was no further uptake of participants for physical testing. Due to the poor uptake in participation, an amendment was submitted to the HREC to allow for recruitment and administration of the self-development questionnaire component of the study only, through an online survey. Once ethical approval for the amendment was obtained, a second phase of recruitment was initiated to recruit more participants to complete the online survey. The online survey remained open for responses from 12 June 2023 to 25 August 2023, and was closed after a three-week period had passed. All responses were recorded in Google Forms and transferred to an Excel spreadsheet prior to statistical analysis.

3.5 Method of Analysis

3.5.1 Data Preparation

All results obtained from the online survey conducted through Google Forms were subsequently exported to an Excel spreadsheet. Additionally, the outcomes of the physical tests were documented in a separate Excel spreadsheet. Following data compilation, the data was cleaned and coded. Units were checked for consistency and converted as deemed essential. Subsequently, average and median values were calculated for the dataset, and percentages were expressed as whole numbers.

3.5.2 Statistical Analysis

Statistical analysis was not conducted due to the limited sample size in this study. Performing both non-parametric and parametric statistics on a small sample size can increase the risk for type II error (Knudson and Lindsey, 2014). Hence, the data will be presented descriptively. The descriptive data included various aspects, such as participant characteristics including gender age, height, body mass, body fat percentage, and other relevant variables. Categorical variables were assessed through the use of frequency tables, while numerical variables were summarised by calculating their means, standard deviations, and ranges.

CHAPTER FOUR: RESULTS

4.1 Recruitment Challenges and Study Sample

The recruitment phase commenced in May 2023. Recruitment advertisements were circulated by motorsport clubs and posted on the Facebook page of Killarney International Raceway. Additionally, they were published in their May circular, which was emailed to their mailing list. One driver-athlete who had seen the recruitment advertisement contacted the researcher to inquire about the study. However, this potential participant was lost during the follow-up process as they did not respond to any further emails. Subsequently, the researcher was invited to appear on an online live talk show called "2nd Gear." The "2nd Gear Live Talk Show" had 4700 registered members and aired every Tuesday evening at 19:00. On 16 May 2023 the study was discussed on the talk show with the hope of recruiting more driver-athletes.

After attending a race day at Killarney International Raceway to personally engage with driver-athletes, we reached out to a total of 82 individuals between 12 May 2023 and 13 July 2023. Nineteen driver-athletes were contacted telephonically, and 63 received an initial email. Of those contacted, 15 driver-athletes initially expressed interest in participating in the study. However, after follow-up communication, only seven were available for physical testing. The limited participation was primarily attributed to time constraints, with some driver-athletes being unavailable due to travel commitments, and one individual having exams during the study period. The seven participants who took part in physical testing and completed the online survey also shared the recruitment advertisement and study information via WhatsApp with their respective club groups, but no other driver-athletes volunteered for the study. The recruitment phase continued until the end of July 2023 with no further uptake by driver-athletes.

After amending the research protocol to administer only the online survey, a second phase of recruitment commenced at the beginning of August 2023 to recruit more driver-athletes to complete the online survey. All previously contacted driver-athletes and stakeholders were contacted again, and a link to the online survey was shared with them. The online survey remained open for responses from 12 June 2023 until 25 August 2023, and 44 more responses to the survey were received. As a result, seven participants were recruited to complete the physical testing part of the study, and 51 respondents were recruited to complete the online survey (Figure 11). All participants completed the consent form, and no responses were excluded. Results will be presented in two separate sections.

The first section will contain the survey responses, and the physical testing results will be presented as a case series.

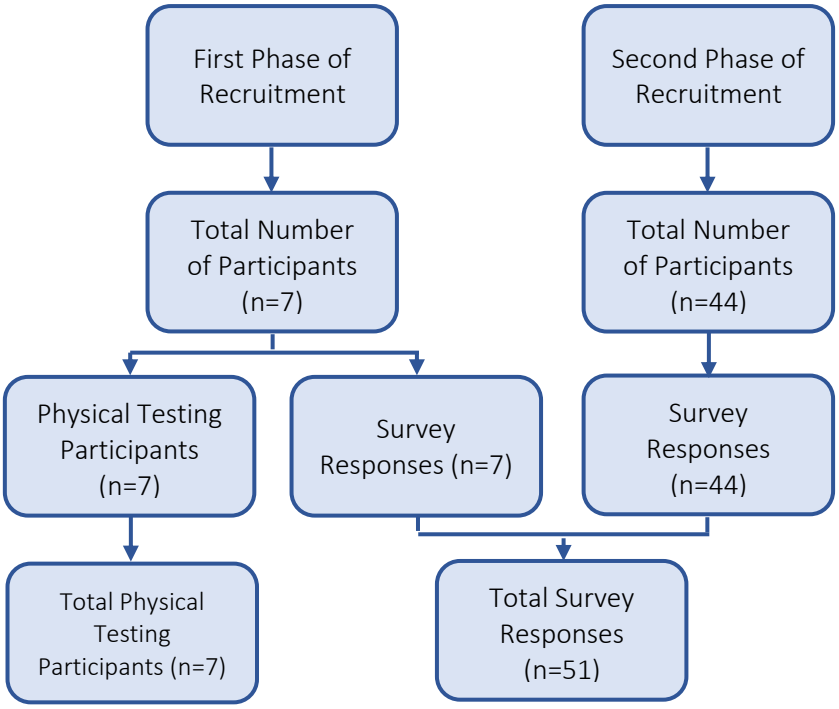

Figure 11. Summary of the Study Sample.

4.2 Survey responses*

4.2.1 Respondent Characteristics

A total of 51 responses to the online survey were recorded and included in the data analysis. Among the included responses, the majority were male respondents with only three (6%) being female. The mean age of the study sample was 45 ± 16 years (range 18-76 years). Twelve respondents (24%) were younger than 30 years old, while nearly half of the study sample, 21 individuals (41%), were over 40 years old. The questions regarding occupation only had 46 responses, as these questions were added to the questionnaire after five responses had already been recorded. None of the respondents reported being unemployed and the majority of respondents were employed full-time (n=21, 41%) or self-employed (n=19, 37%). Among those employed, most worked in the business, consulting, and management sectors. Respondent characteristics are presented in Table 6 below.

* The survey responses included respondents who only completed the online survey and participants who underwent physical testing.

Table 6. Respondent Characteristics including Age in Years, Gender, Employment Status, and Occupation by Sector.

AGE (YEARS)	N	GENDER	N	EMPLOYMENT STATUS	N	OCCUPATION	N
18-28	10 (20%)	**Male**	48 (94%)	**Self-employed**	19 (37%)	**Vehicle Trade and Mechanics**	4 (8%)
28-37	12 (23%)	**Female**	3 (6%)	**Full-time**	21 (41%)	**Accounting, Banking, and Finances**	4 (8%)
38-47	4 (8%)			**Part-time**	1 (2%)	**Business, Consulting, and Management**	18 (34%)
48-57	10 (20%)			**Student**	3 (6%)	**Engineering and Manufacturing**	6 (12%)
58-67	12 (23%)			**Retired**	2 (4%)	**Law**	2 (4%)
68-77	3 (6%)			**Unemployed**	0 (0%)	**Leisure and Sport**	3 (6%)
				No Responses	5 (10%)	**Maintenance**	1 (2%)
						Medical and Sciences	2 (4%)
						Architectural	1 (2%)
						Student	3 (6%)
						Retired	2 (4%)
						No Responses	5 (10%)

4.2.2 Health and Lifestyle Factors

The responses to questions about health and lifestyle factors are presented in Table 7 below. Seven (14%) respondents indicated that they had comorbidities. Among these seven respondents, two had multi-morbidities. One respondent suffered from both cancer and thyroid problems, while another had high blood pressure, high cholesterol, and thyroid problems. Ten (20%) of the respondents were regular smokers and smoked an average of 14 cigarettes per day. Out of the 51 respondents, 30 (59%) consumed alcohol, with 19 (37%) consuming alcohol more than once per week. Thirty-two (63%) respondents indicated that they considered themselves to be eating a healthy and balanced diet. Ninety-four percent (n=48) of the respondents reported having an average of more than five hours of fairly good quality sleep each night.

Table 7. Responses to Questions Regarding Health and Lifestyle Factors.

	YES	NO	UNSURE
Do you smoke?	n=10 (20%)	n=41 (80%)	n=0 (0%)
Do you consume alcohol?	n=30 (59%)	n=19 (37%)	n=2 (4%)
Do you consider yourself eating a health and balanced diet?	n=32 (63%)	n=13 (25%)	n=6 (12%)
Do you suffer from any of the following?			
Diabetes	n=1 (2%)	n=50 (98%)	n=0 (0%)
High Blood Pressure	n=2 (4%)	n=49 (96%)	n=0 (0%)
High Cholesterol	n=2 (4%)	n=48 (94%)	n=1 (2%)
Pulmonary Disorders, Asthma, COPD	n=0 (0%)	n=51 (100%)	n=0 (100%)
Cardiac or Heart Problems	n=1 (2%)	n=50 (98%)	n=0 (0%)
Thyroid Problems	n=2 (4%)	n=49 (96%)	n=0 (0%)
Cancer	n=2 (4%)	n=49 (96%)	n=0 (0%)
Epilepsy	n=0 (0%)	n=51 (100%)	n=0 (0%)
HIV/AIDS	n=0 (0%)	n=51 (100%)	n=0 (0%)
Rheumatoid Arthritis	n=0 (0%)	n=51 (100%)	n=0 (0%)

4.2.3 Motorsport Specific Information

The main category of circuit car racing that most respondents participated in was Clubmans (n=22, 43%). Fifteen (29%) respondents also competed in a second category or in more than one category of circuit car racing. For the 2023 motorsport season, respondents competed at various levels, including social (n=2, 4%), club (n=16, 31%), regional (n=21, 41%), and national (n=10, 20%), with two respondents (4%) not participating in the present season. When looking at the highest level of participation of the respondents' racing careers, eight (16%) respondents competed on an international level. Among the respondents, 39% (n=20) were sponsored. The study sample had a median of 13-14 years of driving experience, with 27% (n=14) having been racing for more than 20 years (Table 8). On average, respondents competed in six races in the previous 12 months.

Table 8. Motorsport Specific Information including Main Category of Participation, Years of Driving Experience, Highest Level of Participation, & Sponsorship.

CATEGORY	N	DRIVING EXPERIENCE (YEARS)	N	HIGHEST LEVEL OF PARTICIPATION	N	SPONSORSHIP	N
Clubmans	22 (43%)	**1-2**	4 (8%)	**Social**	1 (2%)	**Yes**	20 (39%)
Classic Cars	2 (4%)	**3-4**	7 (14%)	**Club**	6 (12%)	**No**	31 (61%)
Fine Cars	2 (4%)	**5-6**	3 (6%)	**Regional**	21 (41%)		
Formula Libre	6 (12%)	**7-8**	3 (6%)	**Provincial**	2 (4%)		
Global Touring Cars	1 (2%)	**9-10**	8 (16%)	**National**	13 (25%)		
GTi Challenge	1 (2%)	**11-12**	3 (6%)	**International**	8 (16%)		
VW Polo Cup	1 (2%)	**13-14**	2 (4%)				
Rallycross	2 (4%)	**15-16**	4 (8%)				
Sports and GT Cars	11 (22%)	**17-18**	1 (2%)				
Thunder Saloons	2 (4%)	**19-20**	2 (4%)				
V8 Masters	1 (2%)	**>20**	14 (27%)				

4.2.4 Training Profiles

4.2.4.1 Physical Activity

According to the World Health Organisation's (WHO) guidelines on physical activity, adults aged 18-64 years should engage in at least 150-300 minutes of moderate-intensity aerobic physical activity per week, or at least 75-150 minutes of vigorous-intensity aerobic physical activity or an equivalent combination of activities in a week (American College of Sports Medicine, 2020). From the survey, 63% (n=32) of respondents indicated that they met the WHO guidelines for physical activity in adults (Table 9).

4.2.4.2 General Conditioning

Fifty-five percent (n=28) of respondents reported that they engaged in regular strength training (Table 9). Fifty-seven percent (n=29) of respondents participated in cardiovascular training and only 25% (n=13) of respondents included flexibility exercises in their training regimen. Twenty-one out of the 51 respondents (41%) indicated that they had also participated in various other sports, including golf, mountain biking, equestrian activities, yacht racing, scuba diving, and running, to name just a few.

Table 9. Responses to Questions Regarding Physical Activity.

	YES	NO	UNSURE
Do you participate in at least 150-300 minutes of moderate-intensity, or 75-150 minutes of vigorous-intensity physical activity per week?	n=32 (63%)	n=14 (27%)	n=5 (10%)
Do you participate in any other sports?	n=20 (39%)	n=31 (61%)	n=0 (0%)
Do you participate in any of the following types of physical activity?			
Strength Training	n=28 (55%)	n=22 (43%)	n=1 (2%)
Cardiovascular Training	n=29 (57%)	n=20 (39%)	n=2 (4%)
Flexibility Training/Yoga	n=13 (25%)	n=37 (73%)	n=1 (2%)
Pilates	n=4 (8%)	n=47 (92%)	n=0 (0%)
CrossFit	n=5 (10%)	n=46 (90%)	n=0 (0%)

4.2.4.3 Motorsport Specific Training

When examining practice sessions on a circuit outside of race days, 43% (n=22) of respondents practiced less than once a month on a circuit outside of race days, and 75% (n=38) did not practice weekly on a circuit.

The average practice session lasted between 61-90 minutes, with respondents completing an average of 12.3 laps in a single practice session. In considering specific exercises and training for motorsport, 80% (n=41) of the respondents reported that they did not engage in any coordination exercises. Seventy-eight percent (n=40) did not incorporate reaction time exercises into their training. Only 24% (n=12) engaged in neck strengthening exercises. Thirty-five percent (n=18) included warm-up exercises in their pre-racing routine. Additionally, 59% (n=30) of respondents did not incorporate stretching or mobility exercises before a race. Seventy-five percent (n=38) spent time visualising and mentally rehearsing before a race. The types of exercises specific to motorsport that respondents participated in is summarised in Table 10.

Table 10. Responses to Questions Regarding Motorsport Specific Training.

	YES	NO	UNSURE
Do you use any racing simulator software for training?	n=18 (35%)	n=33 (65%)	n=0 (0%)
Do you do any warm-up before going out onto the circuit to race?	n=18 (35%)	n=33 (65%)	n=0 (0%)
Do you do any stretches or mobility exercises before going out onto the circuit to race?	n=21 (41%)	n=30 (59%)	n=0 (0%)
Do you spend any time visualising or mentally rehearsing before a race?	n=38 (75%)	n=13 (25%)	n=0 (0%)
Do you engage in any of the following?			
Coordination Exercise	n=9 (18%)	n=41 (80%)	n=1 (2%)
Reaction Time Exercises	n=10 (20%)	n=40 (78%)	n=1 (2%)
Neck Strengthening Exercises	n=12 (24%)	n=38 (74%)	n=1 (2%)

4.3 Reported Injuries

4.3.1 Overall Injury Reporting

In the study, a total of 31 injuries were reported by respondents, comprising 10 current injuries and 21 past injuries (Table 11). The predominantly affected area was the foot/ankle (n=8, 26%). Regarding the types of injuries sustained, fractures (n=9, 29%) were the most common. Forty-two percent of injuries (n=13) were sustained during a car accident. Notably, among the 13 injuries sustained during car accidents, nine occurred during competition, while three occurred during motorsport-specific training.

4.3.2 Current Injuries

For the purpose of the online survey, a current injury was defined as an injury sustained in the past three months or one currently being experienced. One current injury was sustained during a car accident when performing motorsport specific training. Five of the 10 injuries had an acute or sudden onset. The treatment of these current injuries primarily involved treatment by a doctor, self-treatment, medication, and surgical procedures. The duration of time respondents were unavailable for training or competition due to their injuries ranged from no days missed (n=3), 1-7 days (n=3), and more than 28 days missed (n=4).

4.3.3 Past Injuries

A past injury was defined as an injury sustained four or more months ago. Respondents reported a total of 21 past injuries. Most of the past injuries reported were traumatic in nature, with eight out of the 21 injuries being fractures, one dislocation/subluxation, one nerve injury, three ligament injuries, and one concussion. Twelve of the past injuries were sustained during car accidents, with nine occurring during competition. The majority of past injuries were treated by physiotherapists, followed by doctors, and medication. Two injuries required surgical treatment. Nine out of the 21 injuries left respondents unavailable for training or competition for more than 28 days.

Table 11. Injuries Reported.

	CURRENT INJURIES	PAST INJURIES	TOTAL
TOTAL	n=10	n=21	n=31 (100%)
AREA OF INJURY			
Head	n=0	n=1	n=1 (3%)
Neck	n=0	n=2	n=2 (6%)
Shoulder	n=1	n=3	n=4 (13%)
Elbow	n=0	n=1	n=1 (3%)
Wrist/Hand	n=1	n=1	n=2 (6%)
Chest/Trunk	n=0	n=2	n=2 (6%)
Rib/Thorax	n=0	n=1	n=1 (3%)
Lower Back	n=1	n=2	n=3 (10%)
Knee	n=3	n=4	n=7 (23%)
Foot/Ankle	n=4	n=4	n=8 (26%)
TYPE OF INJURY			
Nerve	n=1	n=1	n=2 (6%)
Dislocation/Subluxation	n=1	n=1	n=2 (6%)
Fracture	n=1	n=8	n=9 (29%)
Ligament	n=4	n=3	n=7 (23%)
Tendon	n=2	n=0	n=2 (6%)
Muscle	n=1	n=2	n=3 (10%)
Bruise/Contusion	n=0	n=1	n=1 (3%)
Inflammation/Swelling	n=0	n=1	n=1 (3%)
Concussion	n=0	n=1	n=1 (3%)
Unsure	n=0	n=3	n=3 (10%)
CAUSE OF INJURY			
Acute/Sudden Onset	n=5	n=6	n=11 (35%)
Chronic/Overuse	n=4	n=3	n=7 (23%)
Car Accident	n=1	n=12	n=13 (42%)
TYPE OF ACTIVITY AT THE TIME OF INJURY			
Motorsport Specific Training	n=1	n=2	n=3 (10%)
Competition	n=0	n=9	n=9 (29%)
Other Physical Activity	n=6	n=7	n=13 (42%)
Other	n=3	n=3	n=5 (16%)

n refers to injury numbers and the percentage is calculated from the total number of injuries reported.

4.4 Case Series*

4.4.1 Participant Characteristics

The physical characteristics of the individual participant are summarised in Table 12. All participants were male and right hand dominant. Participants' mean age was 40 ± 14 years (range: 22-63 years), the mean body mass was 88 ± 10 kg (range: 75-105 kg), and mean stature was 183 ± 11 cm (range 169-201 cm). Participants had a mean BMI of 26 ± 3 (range: 22-30) and a mean waist circumference of 96 ± 8 cm (range: 91-109 cm). Participants' mean sum of seven skinfolds was 114 ± 56 (range: 40-213) with a mean body fat percentage of 17 ± 8% (range: 9-32%).

Table 12. Physical Characteristics of Participants.

PARTICIPANT	1	2	3	4	5	6	7
Age (years)	34	56	37	63	22	37	34
Body Mass (kg)	93	75	105	92	91	77	84
Stature (cm)	201	183	188	175	190	169	175
Waist Circumference (cm)	91	91	107	109	92	95	91
BMI (kg/m^2)	23	22	30	30	25	27	27
Sum of Seven Skinfolds	102	40	158	213	86	102	94
Body Fat %	15	9	26	32	12	16	12

4.4.2 Health and Lifestyle Factors

Among the seven participants, only one was a smoker, while six consumed alcohol. Furthermore, only one participant mentioned that they did not consider their diet to be healthy and balanced. None of the participants reported having any comorbidities or lifestyle diseases. All respondents reported having an average of more than five hours of average to good quality sleep in a night. The responses of participants to questions regarding their health and lifestyle factors are summarised in Table 13 below.

* For completeness of the case series, we are reporting the motorsport specific and training information of this cohort separately even though this data has also been included in Section 4.2.

Table 13. Responses to Questions Regarding Health and Lifestyle Factors.

PARTICIPANTS	1	2	3	4	5	6	7
Do you smoke?	No	No	No	No	No	Yes	No
How often do you consume alcohol?	Never/I don't drink	< once a week	< once a week	5-6 times a week	< once a week	3-4 times a week	1-2 times a week
Do you consider yourself eating a health and balanced diet?	Yes	Yes	Yes	Yes	Yes	No	Yes
Do you suffer from any of the following?							
Diabetes	No	No	No	No	No	No	No
High Blood Pressure	No	No	No	No	No	No	No
High Cholesterol	No	No	No	No	No	No	No
Pulmonary Disorders, Asthma, COPD	No	No	No	No	No	No	No
Cardiac or Heart Problems	No	No	No	No	No	No	No
Thyroid Problems	No	No	No	No	No	No	No
Cancer	No	No	No	No	No	No	No
Epilepsy	No	No	No	No	No	No	No
HIV/AIDS	No	No	No	No	No	No	No
Rheumatoid Arthritis	No	No	No	No	No	No	No

4.4.3 Motorsport Specific Information

Motorsport specific information of the participants is presented in Table 14. Three participants raced in the Sports and GT cars category and two participants also competed in the South African Endurance Series. Six out of the seven participants had more than nine years of driving experience. In the present 2023 motorsport season, three participants competed at national level. When considering the highest level of participation in their racing careers, four participants had competed nationally. Further, four of the participants were sponsored driver-athletes.

Table 14. Motorsport specific information including Primary and Secondary Category of Participation, Years of Driving Experience, Current and Highest Level of Participation, and Sponsorship.

PARTICIPANT	1	2	3	4	5	6	7
Category	Thunder Saloons	Sports & GT Cars	Sports & GT Cars	Classic Cars	Formula Libre	Fine Cars	Sports & GT Cars
Second Category	N/A	N/A	N/A	Endurance Series	Endurance Series	N/A	N/A
Driving Experience (Years)	>20	9-10	11-12	>20	19-20	15-16	3-4
Current Level of Participation	National	Club	National	Club	National	Club	Regional
Highest Level of Participation	National	National	National	Regional	National	Club	Regional
Sponsorship	Yes	No	No	No	Yes	Yes	Yes

4.4.4 Training Profiles

4.4.4.1 Physical Activity

Two participants indicated that they did not engage in at least 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity physical activity per week, as outlined by the WHO guidelines for physical activity for adults (Table 15).

4.4.4.2 General Conditioning

Both participants who did not meet the WHO guidelines for physical activity in adults also abstained from engaging in any other types of training or physical activity. More than half of the participants participated in strength training, cardiovascular training, and flexibility exercises. Additionally, participant five was involved in CrossFit and participated in mountain biking.

Table 15. Responses to Questions Regarding Physical Activity.

PARTICIPANTS	1	2	3	4	5	6	7
Do you participate in at least 150-300 minutes of moderate-intensity, or 75-150 minutes of vigorous-intensity physical activity per week?	No	Yes	Yes	Yes	Yes	No	Yes
Do you participate in any other sports?	No	No	No	No	Yes	No	No
Do you participate in any of the following types of physical activity?							
Strength Training	No	Yes	Yes	Yes	Yes	No	Yes
Cardiovascular Training	No	Yes	Yes	Yes	Yes	No	No
Flexibility/Yoga	No	Yes	Yes	Yes	Yes	No	No
Pilates	No	No	No	No	No	No	No
CrossFit	No	No	No	No	Yes	No	No
Strength Training	No	Yes	Yes	Yes	Yes	No	Yes

4.4.4.3. Motorsport Specific Training

The responses of individual participants to questions regarding motorsport-specific training are presented in Table 16. The pre-race routine of most participants included stretches or mobility exercises, with two participants performing other warm-up activities before heading out onto the race circuit. One participant reported that they did not spend time visualising or mentally rehearsing before a race. Participant five was the only one who engaged in any coordination and neck strengthening exercises.

Table 16. Responses to Questions Regarding Motorsport Specific Training.

PARTICIPANTS	1	2	3	4	5	6	7
Do you use any racing simulator software for training?	No	No	Yes	No	Yes	No	No
Do you do any warm-up before going out onto the circuit to race?	Yes	No	Yes	No	No	No	No
Do you do any stretches or mobility exercises before going out onto the circuit to race?	Yes	Yes	Yes	Yes	Yes	No	Yes
Do you spend any time visualising or mentally rehearsing before a race?	Yes	Yes	Yes	Yes	No	Yes	Yes
Do you engage in any of the following?							
Coordination Exercise	No	No	Unsure	No	Yes	No	No
Reaction Time Exercises	No	No	Unsure	No	No	No	No
Neck Strengthening Exercises	No	No	No	Unsure	Yes	No	No

4.4.5 Reported Injuries

Participant one reported a current acute ligament injury to the knee, which occurred during motorsport-specific training. Unfortunately, no treatment was sought, and this injury resulted in an absence from training and competition lasting more than 28 days. He reported no pain or problems with the knee on the day of physical testing.

Participant three had a past knee injury, although the type of injury was uncertain. It was classified as a chronic or overuse injury and was successfully managed by a physiotherapist, without any disruptions to their training or competition schedule.

Participant six reported a past shoulder injury, the exact type of which remained uncertain. This injury was acutely acquired during a car accident while they were engaged in farm work. Treatment involved medication, and no training or competition days were missed as a result.

4.4.6 Physical Tests

Each participant underwent eight physical tests. Figure 12 displays the results for the coordination tests, reaction time, and VO_2 max. The wall toss test measuring hand-eye coordination yielded a mean of 20 ± 4 successful catches, with a range of 15 to 24 catches for participants. The foot step test that was used to measure lower limb coordination showed mean results of 49 ± 6 touches for the left side and 54 ± 7 touches for the right side.

The ruler drop test was used to measure reaction time. Interestingly, reaction times for participants on the right and left sides were similar, with a mean of 0.19 ± 0.02 seconds for both sides in the sample. The 20m shuttle run test was used to estimate VO_2 max and the mean estimated VO_2 max for participants was 30 ± 4 ml/kg/min, with a range of 26 to 36 ml/kg/min.

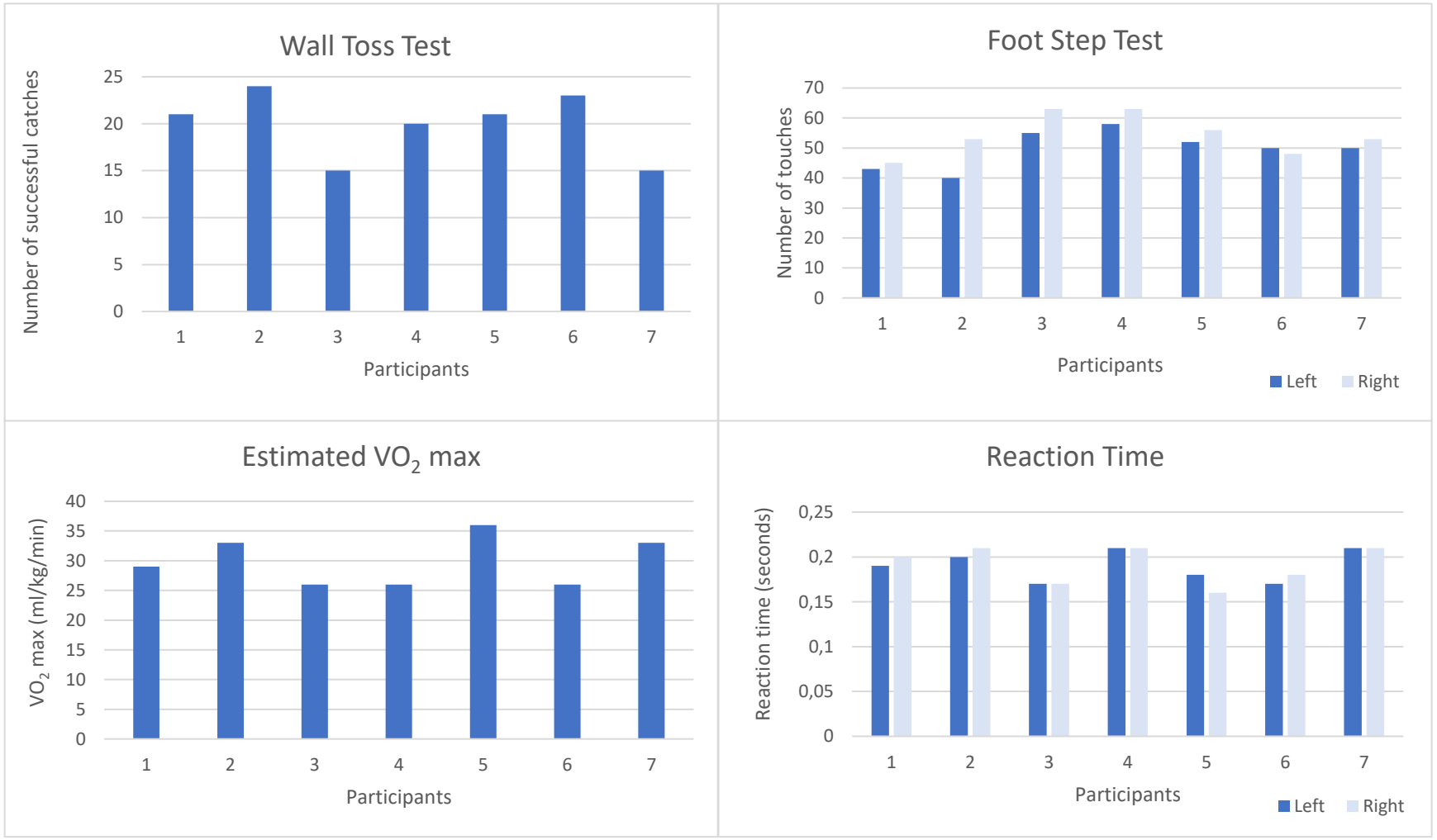

Figure 12. Physical Tests Results of Participants for the Wall Toss Test, Foot Step Test, Reaction Time, and Estimated VO_2 Max.

The results for the single-leg heel raise test, grip strength, neck flexor endurance test, and CKCUEST are displayed in Figure 13 below. The single-leg heel raise test measured plantar flexion endurance strength. Participants had a higher mean for the single-leg heel raise test on the right side (20 ± 6) compared to the left side (18 ± 4). Three of the seven participants (participant two, three, and five) performed more heel raises on the left side than on the right.

Regarding grip strength, there was only a 4 kg difference between the mean scores for left and right grip strength measurements. The mean for grip strength on the left side was 54 ± 10 kg, while the mean for grip strength on the right side was 58 ± 10 kg. Notably, participant five achieved the highest grip strength scores, with 74 kg on the left and 72 kg on the right side.

For the neck flexor endurance test, the sample exhibited a wide range, with a minimum of 30 seconds and a maximum of 122 seconds. The mean endurance time for participants was 58 ± 30 seconds. The CKCUEST test assessed the stability of the upper limbs in a closed kinetic chain and yielded a mean score of 21 ± 3 (range 16 to 24) touches.

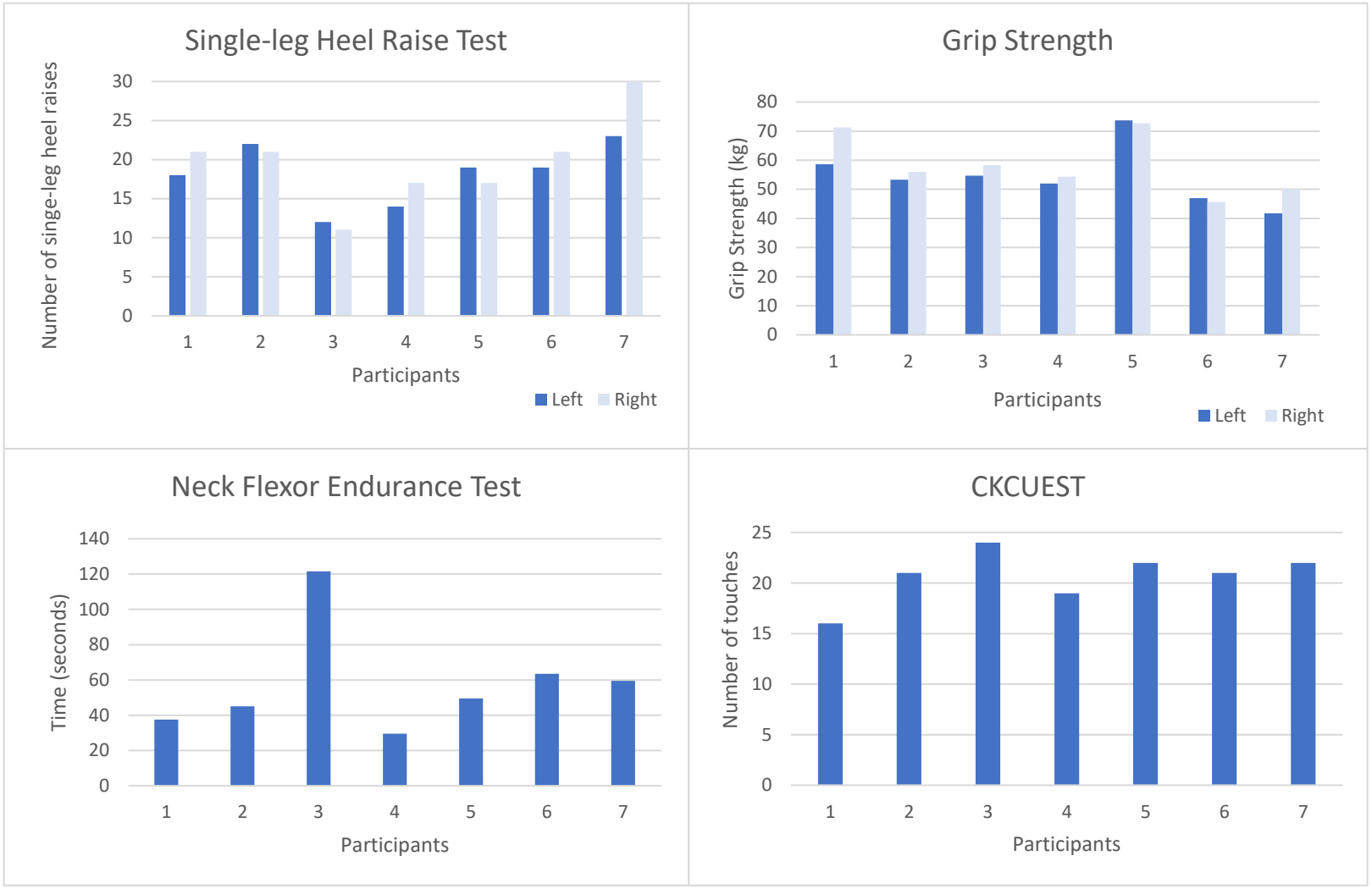

Figure 13.Physical Tests Results of Participants for the Single Leg Heel Raise Test, Grip Strength Test, Neck Flexor Endurance Test, and CKCUEST.

4.5 Summary of Results

A total of 51 responses from the online survey were included for analysis. Of these respondents, 6% were female, while 94% were male. Fourteen percent of the respondents reported suffering from comorbidities or illnesses. Twenty percent were smokers, and 59% consumed alcohol. The primary racing category in which the respondents participated was Clubmans, followed by Sports and GT Cars, and Formula Libre. Respondents competed at various levels of racing, with the majority (41%) competing at regional level. Most respondents did not regularly practice on a circuit, with 43% practicing on a circuit outside of race days less than once a month. During their practice sessions on the circuit, the average duration was 61-90 minutes, with an average of 12.3 laps completed in a single session. Most respondents did not include coordination exercises, reaction time exercises, or neck-strengthening exercises in their training routines.

More than half of the respondents did not perform any warm-up or stretching/flexibility exercises before a race or competition. Seventy-five percent spent time visualising or mentally rehearsing before a race. Sixty-three percent of the participants met the WHO guidelines for physical activity in adults, and more than half of the respondents engaged in regular cardiovascular and strength training. When examining reported injuries, the most commonly affected body part was the foot/ankle, with fractures being the most common type of injury sustained. In total, 13 of the 31 injuries reported were sustained during a car accident, with most car accidents occurring during competition.

Seven participants completed the physical tests. All seven participants were male and right dominant, with a mean age of 40 years. None of the participants reported having any illnesses or comorbidities. Three of the seven participants competed in the Sports and GT cars category, with two participants also competing in the South African Endurance Series. The majority of participants met the WHO guidelines for physical activity in adults, and more than half participated in strength training, cardiovascular training, and flexibility exercises. One participant engaged in coordination and neck-strengthening exercises, and none of the participants performed any reaction time exercises. Participant one reported one current injury, while participants three and six reported one past injury each.

There was no significant difference in left and right-sided measurements for plantarflexion strength, grip strength, lower limb coordination, or reaction times among the participants. For the neck flexor endurance test, the sample exhibited a wide range. The study sample of seven had a mean estimated VO_2 max of 30 ml/kg/min.

CHAPTER FIVE: DISCUSSION

5.1 Recruitment Challenges and Study Sample

The study sample comprised of 51 respondents who participated in the online survey, and seven individuals who underwent physical testing. This was achieved through a two-phase recruitment process spanning four months. Despite diligent recruitment efforts, the desired sample size of 52, required to attain 80% statistical power, was not achieved. The sample exhibited a marked male predominance, with only three female respondents (6%). This finding is consistent with the prevailing gender dynamics in South African motorsport, where the sport remains male dominated.

During the initial phases of the study, when engaging with pertinent stakeholders to discuss the study's aims and objectives, there was a notable expression of interest in the research. Particularly, stakeholders associated with motorsport, although not as driver-athletes themselves, exhibited strong support for research within motorsport in South Africa and demonstrated a willingness to help. However, as the study advanced, both stakeholders and athlete participants who had initially expressed their willingness to contribute gradually lost interest. Additionally, they encountered difficulties in recruiting driver-athletes who were willing to participate in physical testing, resulting in a substantial number discontinuing their involvement in the research process.

When reflecting on engagements with stakeholders and driver-athletes, common themes that emerged were that driver-athletes may not have perceived physical fitness as a prerequisite for performance or injury prevention in motorsport. Some opinions shared by driver-athletes suggested that success in motorsport was not dependent on the physical condition of the driver-athlete or their driving skills, but rather on the financial resources invested in the car and its speed. Additionally, there may be a greater perceived significance of mental preparation over physical readiness for competitive racing or events.

An email received from one of the participants further underscored these sentiments, stating:

> If you take 25 drivers from Sport and GT, I am pretty certain they are not fitness fanatics, in-fact some are well overweight but they manage to race their cars successfully. In short, I don't believe you need to exercise to compete at club level of motorsport. I cannot pass comment on the bike racers but would think their input would be a lot more rigorous than ours during a race.

This email highlighted three pertinent considerations. Firstly, it suggests that robust physical fitness may not be universally essential for all driver-athletes across diverse motorsport categories. Secondly, it raises the possibility that performance might not hold equal importance for all driver-athletes, with many engaging in motorsport as a leisure pursuit. Thirdly, it calls into question the generalisability of the research findings to the entire South African motorsport population, implying that the study may have inadvertently focused on a subset of driver-athletes not representative of the broader motorsport landscape. It is plausible that conducting research in motocross or motorcycle racing, as opposed to circuit car racing, would yield markedly different results. The present research highlighted that further exploration of driver-athletes' perceptions and understanding of physical fitness and injury prevention is needed.

It also became apparent that a substantial proportion of driver-athletes held positions within the business sector or were business owners, as will be discussed in the subsequent section. A notable contention among these individuals was the challenge of allocating an hour of their daily schedules for participation in physical testing. Furthermore, a significant segment of the driver-athlete population resided abroad or engaged in frequent international travel, rendering them unavailable for the testing procedures.

At the time of the present study, there was no existing research or published literature about motorsport in South Africa that the researchers were aware of. Consequently, this domain may have represented uncharted territory for both driver-athletes and stakeholders. It is possible that this lack of prior research could have contributed to the limited interest in this type of research. Stakeholder engagement was undertaken during the initial phase of research protocol development; however, the present findings illuminated the necessity to initiate stakeholder engagement at an even more fundamental level. It became evident that there was a need to first understand the perceptions of research among driver-athletes and study participants. Perhaps a critical point of inception lies in introducing the concept of research at a grassroots level within the motorsport community.

5.2 Survey Responses

5.2.1 Respondent Characteristics

The older average age of the sample signified that the study's cohort of circuit car driver-athletes predominantly comprised individuals of a relatively advanced age. The most senior participant in the sample was 76 years old, emphasising the observation that driver-athletes often continue their involvement in motorsport well into their later years (Potkanowicz, 2019).

It is noteworthy that all three female respondents were young driver-athletes, aged 21, 23, and 23 years respectively. This trend may serve as an indicator of the growing presence of female driver-athletes in recent years (Reid and Lightfoot, 2019; Potkanowicz and Mendel, 2013). Although men continue to dominate the field of driver-athletes and other professional roles in motorsport globally, there is a noticeable increase in women's involvement in motorsport (Kochanek *et al.*, 2021).

It is widely acknowledged that motorsport is an inherently expensive and globally influential sport (Grant-Braham, 2009). Participation necessitates ownership of a car or access to a sponsored vehicle, often accompanied by the substantial financial commitments required for car maintenance, repairs, transportation to races, and the procurement of fuel. Furthermore, it is a common observation that as one ascends the tiers of motorsport, the cost of the cars involved typically increases. Therefore, it is reasonable to theorise that financial stability is a prerequisite for active engagement in motorsport. None of the respondents who completed questions on occupation in this study reported experiencing unemployment. Among those who were not engaged in full-time or self-employment, two out of the three student respondents indicated that they received financial support in the form of sponsorship. Additionally, the respondent who was employed part-time was primarily a professional athlete and was also sponsored.

5.2.2 Health

Seven respondents reported comorbidities. These diagnoses included a spectrum of health issues, ranging from common conditions such as high cholesterol, to more severe illnesses including cancer. Despite these medical diagnoses, all respondents maintained active participation in motorsport. There was a notable variation in the smoking habits among the 20% of respondents who reported being regular smokers. The respondent with the lowest smoking frequency reported an average consumption of two cigarettes per day, while at the opposite end of the spectrum, one respondent exhibited a particularly high daily smoking rate, averaging 30 cigarettes per day.

A significant proportion of the respondents reported regular alcohol consumption, with 37% indicating alcohol intake more than once per week. Among these respondents, five exhibited regular alcohol consumption patterns, with one reporting alcohol consumption 5-6 days per week, and four indicating daily alcohol consumption. These five respondents shared a common characteristic, all being aged 50 years or older. When examining the dietary habits of the sample, more than half of respondents reported adhering to a healthy and balanced diet. Additionally, 12% expressed uncertainty regarding their dietary habits.

This uncertainty may suggest a lack of clarity among respondents regarding what constitutes a balanced and healthy diet, potentially introducing ambiguity into the assessment of the dietary practices of the study sample.

On the topic of sleep patterns, 94% of respondents reported an average nightly sleep duration exceeding five hours. Furthermore, almost half of respondents reported getting more than six hours of sleep per night on average. The sleep patterns of the respondents were generally characterised by fairly restful to sound sleep.

While most participants did not report any comorbidities or chronic lifestyle diseases, it is important to note that the absence of such reports does not necessarily indicate overall good health. One limitation of this study was our inability to assess the BMI of the study sample who completed the online survey, which could have provided valuable insights into their overall health status.

5.2.3 Motorsport Specific Information

The primary category of circuit car racing in which the study sample participated was Clubmans, followed by Sports and GT Cars. It is worth noting that this distribution could have introduced a sampling bias, as specific stakeholders involved in recruitment were associated with these particular categories of circuit car racing. While this research aimed to report information on the specific classes within these categories and the types of cars respondents drove, the variations in class specifications across categories, and a lack of comprehensive knowledge by the primary investigator on this aspect, prevented a direct link to overall performance from being established and, consequently, this information could not be reported.

For the present 2023 motorsport season, two respondents were not participating at the time of data collection. Notably, these two respondents did not have any reported injuries preventing their participation, suggesting alternative reasons for their non-participation. When investigating the highest level of participation and sponsorship, no significant association could be observed. These findings may indicate that sponsorship in motorsport may not necessarily be contingent on performance or achievements, and not all driver-athletes competing at higher levels received sponsorship.

When assessing the potential association between the level of racing and years of driving experience, six of the eight respondents who had competed at an international level possessed more than 20 years of driving experience. However, it is important to recognise that no clear-cut relationship emerged, as drivers with extensive driving experience also participated in lower levels of racing. This observation may underscore the multifaceted motivations of driver-athletes in motorsport, where participation extends beyond mere achievement to encompass recreational enjoyment.

Examining respondents under the age of 30 who possessed significant driving experience, it was noted that several of these respondents initiated their racing careers at the early ages of eight to nine years, with one individual having been introduced to motorsport participation at as early as two to three years of age. This observation aligns with the existing literature that substantiates the commencement of competitive involvement in motorsport at as young as 10 years old (Seiffert, Szymski and Krutsch, 2020).

Three respondents did not participate in any races during the previous 12 months, while one respondent stood out by competing in 25 races within the same timeframe. What is worth noting is that this high-participation individual also happened to own a race car parts store and workshop situated at the Killarney circuit, which likely gave him unique access to necessary components and the ability to personally maintain his vehicle. Another significant finding was that eight (16%) respondents reported being involved in a car accident during the previous 12 months. It is important to emphasise that no apparent relationship could be established between those who experienced car accidents and their age or level of driving experience.

Lastly, 20 (39%) respondents reported the utilisation of cooling techniques either before, during, or after a race. These methods included practices such as cold air exposure, consumption of cold water and energy drinks, the adoption of cooling undergarments, and the application of chest coolers or ice packs. Notably, one respondent offered a valuable insight, highlighting that temperature management became more manageable with accumulated experience.

5.2.4 Training Profiles

5.2.4.1 Physical Activity

A significant portion of the respondents in the study adhered to the physical activity guidelines established by the WHO for adults, while 10% expressed uncertainty regarding their compliance with these guidelines. It is plausible that a lack of awareness regarding the specific recommendations for physical activity in adults exists among driver-athletes.

5.2.4.2 General Conditioning

Almost half of the participants did not engage in either strength or cardiovascular training. These training modalities bear particular significance in the context of injury prevention, encompassing both acute, chronic, as well as overuse injuries (Hoyes and Collins, 2018; Seiffert, Szymski and Krutsch, 2020; Backman *et al.*, 2005). Furthermore, 41% also actively participated in other forms of physical activity or sports. These activities encompassed a diverse range including, but not limited to, mountain biking, cricket, golf, padel, squash, equestrian pursuits, and even yacht racing.

5.2.4.3 Motorsport Specific Training

Participants did not regularly practice on a circuit outside of race days. These findings suggest that motorsport in South Africa primarily revolves around weekend events, with driver-athletes dedicating limited time to practice sessions outside of competitive racing. Several factors may contribute to this phenomenon, including potential time constraints during weekdays and the financial burden associated with transporting vehicles to the circuit for practice, and the costs associated with driving the cars during practice sessions. Notably, there appears to be no discernible relationship between the frequency of practice sessions and the level of participation of respondents.

When assessing the incorporation of specific exercises and training practices within the realm of motorsport, a significant proportion of respondents did not include these elements in their training regimens. Previous research has highlighted the importance of coordination, sensorimotor skills, rapid reaction times, and robust neuromuscular control among driver-athletes to mitigate the risk of direct trauma and musculoskeletal injuries (Baur *et al.*, 2006). Furthermore, evidence suggests that enhanced neck strength can play a pivotal role in reducing the incidence of sports-related concussions (McKnight *et al.*, 2019). It is a matter of concern that a substantial number of respondents did not engage in these specific exercises. Possible explanations for this trend could be a lack of awareness regarding the benefits associated with these exercises, leading them to be perceived as non-essential or low-priority components of their training routines.

When examining preparatory practices within the motorsport context, a modest proportion of respondents reported engaging in warm-up exercises prior to racing. A slightly larger subset of participants incorporated some form of a stretching or mobility routine as part of their pre-race preparations. As previously highlighted, it is evident that respondents assigned a greater emphasis to mental preparation in motorsport. This is supported by the results that a substantial majority, amounting to 75%, allocated time to engage in visualisation and mental rehearsal before each race, thereby possibly reflecting a higher priority placed on psychological and mental readiness over physical conditioning.

5.2.5 Reported Injuries

Forty-two percent of injuries reported in this study were sustained during a car accident. A prior investigation into injuries sustained during and after races in circuit car racing, conducted by Minoyama and Tsuchida (2004), indicated that the most commonly affected body sites were the neck, lower limbs, and upper limbs. This diverges from the present findings, which suggested that the foot/ankle, shoulder, chest/trunk, and lower back were the most affected in car accidents during motorsport-related activities. Neck injuries comprised a mere 6% (n=2) of our results, with no neck injuries sustained during car accidents. When considering other forms of motorsport such as rally racing, the most commonly reported issues were related to the lumbar spine, cervical spine, shoulders, and thoracic spine (Mansfield and Marshall, 2001). In contrast, an investigation into stock car drivers revealed that back and torso injuries were the most commonly reported problems (Ebben and Suchomel, 2012).

Regarding the types of injuries sustained, fractures and ligament injuries were the most prevalent in this study, followed by muscle injuries. This contrasts with the existing literature on circuit car racing. Minoyama and Tsuchida (2004) reported that bruises were the predominant injury in single-seat car racing, and neck sprains were the most common injury in saloon car racing. Fractures constituted 8% of saloon car racing injuries, and no fractures were reported in single-seat car racing (Minoyama and Tsuchida, 2004). Previous research has highlighted abrasions and contusions as the most common acute injuries in four-wheeled motorsports, with more severe injuries occurring in traumatic accidents (Seiffert, Szymski and Krutsch, 2020).

Additionally, Gorove (2012) emphasised head injuries as the most frequent type of injury sustained during traumatic accidents in motorsport events. It is worth noting that the present study only had one respondent who reported a head injury, specifically a concussion sustained during a car accident.

Recent advancements in safety equipment and protective gear may explain the reduced incidence of neck and head injuries in motorsport (Seiffert, Szymski and Krutsch, 2020; Patalak *et al.*, 2020). The present findings align more closely with what has been previously reported in motorcycle racing. Tomida *et al.* (2005) reported that the most common injuries in motorcycle racing in Japan were fractures, ligament injuries, dislocations, and soft tissue injuries.

Similarly, Zasa *et al.* (2016) documented that fractures were the most common injury in the 2014 MotoGP season, followed by joint dislocations. Our study revealed that 23% of the overall reported injuries were classified as overuse or chronic injuries. These overuse or chronic injuries affected various anatomical areas, including the foot/ankle, neck, knee, and lower back, with no instances reported in the upper limbs. The existing literature indicates that driver-athletes are susceptible to overuse musculoskeletal injuries, which can stem from various factors (Baur *et al.*, 2010; Ebben and Suchomel, 2012). Common complaints among driver-athletes have included shoulder fatigue, arm soreness, hand fatigue, and neck pain (Ferguson, 2018; Minoyama and Tsuchida, 2004). Moreover, Baur *et al.* (2010) reported that up to 70% of all driver-athletes experienced lower back pain at some point in their careers. From the present results, the proportion of overuse or chronic injuries was relatively low, and no upper limb symptoms were reported. However, the chronic/overuse injuries identified did include two neck injuries and one lower back injury, aligning with complaints documented in the existing literature.

Among the 13 injuries sustained during car accidents, 62% occurred during competition, while 23% occurred during motorsport-specific training. This observation suggests that driver-athletes may exhibit more aggressive driving behaviours during competitions, possibly driven by the desire for enhanced performance and better results. The majority of the reported injuries could be managed conservatively, with surgery required for only 13% of cases. This finding may indicate that injuries in circuit car racing tend to be of a less severe nature, reinforcing the notion that injuries in four-wheeled motorsports are generally classified as less severe, requiring less complex treatment (Seiffert, Szymski and Krutsch, 2020).

Given the present study's limited sample size and relatively low number of injuries reported, definitive conclusions cannot be drawn. No correlations were observed between the risk of injury and factors such as age, years of driving experience, or racing category. Additionally, no significant associations were identified between injury risk and respondents' physical activity or training practices.

Notably, among the three respondents who reported neck injuries or a concussion, none engaged in neck strengthening exercises. However, no statistically significant correlation between injury risk and motorsport-specific exercises was established. The substantial disparities in injury incidence and prevalence across the motorsport literature may stem from inconsistent injury definitions and classifications used in research. The lack of standardised injury reporting methods hinders the comparability of studies and impedes the development of comprehensive insights into motorsport-related injuries.

5.3 Case Series

5.3.1 Participant Characteristics

This study sample's age distribution, with a mean of 40 ± 14 years, is older in comparison to participant samples in other studies focusing on various aspects of motorsport. Baur *et al.* (2006) conducted a study comparing reaction time, stability, performance capacity, and strength performance among elite racing drivers, comparing them with age-matched, physically active controls. In their research, the driver sample had an average age of 27 ± 5 years (Baur *et al.*, 2006). Similarly, Backman *et al.* (2005) delved into neuromuscular performance characteristics in experienced international-level open-wheel and rally drivers, citing a mean age of 22 ± 4 years for their open-wheel driver group. Furthermore, Baur *et al.* (2010) investigated maximal trunk extensor and flexor strength in elite race car drivers and physically active controls, noting a mean age of 29 ± 4 years for their elite race car driver group.

Likewise, McKnight *et al.* (2019) conducted a comparative analysis of physical fitness variables among elite-level race car drivers from various competitive championships. Their study revealed mean ages of 25 ± 5, 29 ± 4, and 36 ± 7 years for their groups of Formula 1, IndyCar, and IMSA GTD drivers, respectively. Lastly, Raschner, Platzer and Patterson (2013) explored selected fitness parameters among experienced and junior open-wheel race car drivers, with the group of elite race car drivers having a mean age of 26 ± 5 years. Considering the survey respondents' age in the present study, as well as the mean age of participants who underwent physical testing, it is plausible to hypothesise that the population of circuit car driver-athletes in South Africa exhibits an older demographic profile when compared to other populations of circuit car driver-athletes.

When comparing the body mass and stature of the present respondent sample to other studies, the sample exhibited a higher average body mass and stature. For instance, in Baur et al.'s study (2006), the mean body mass was 69 ± 8 kg, and the mean stature was 177 ± 4 cm.

Similarly, the study by Backman *et al.* (2005) reported similar values with a mean body weight of 68 ± 7 kg and a mean stature of 177 ± 4 cm. Baur *et al.* (2010) recorded slightly higher values with a mean weight of 71 ± 8 kg and a mean stature of 178 ± 6 cm. The present respondent sample also exhibited an exceptionally higher mean BMI of 26 ± 3, when compared to other studies who reported mean BMI values of 22 ± 2, 23 ± 2, and 23 ± 2 (Baur *et al.*, 2010; Backman *et al.*, 2005; Raschner, Platzer and Patterson, 2013).

Moreover, it is worth noting that only one other study reported body fat percentage, revealing a mean body fat percentage of 8 ± 3% for their sample of open-wheel driver-athletes (Backman *et al.*, 2005). This figure significantly contrasts with the mean body fat percentage of our participant sample, encompassing a wide range of values from 9% to 32%. Participant one, two, five, six, and seven had a body fat percentage ranging from good to excellent, while participant three and four had poor and very poor body fat percentages according to the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 2020). It is noteworthy that participant two, who had the lowest body fat percentage and a waist circumference of 91 cm, engaged in weekly training sessions with a biokineticist to maintain physical fitness.

No other studies have reported on waist circumference. Abdominal obesity is generally associated with an increased risk of morbidity and mortality. Traditionally, the BMI has been employed as an indicator of body size and composition, but alternative measures such as waist circumference have been proposed as superior indicators of abdominal adiposity. Our study sample exhibited a mean waist circumference of 96 cm. Notably, participants three and four displayed significantly larger waist circumferences, measuring 107 cm and 109 cm, respectively.

It is pertinent to mention that all of the aforementioned studies were conducted on experienced driver-athletes (Raschner, Platzer and Patterson, 2013), driver-athletes competing in competitive championships (McKnight *et al.*, 2019), elite race car drivers (Baur *et al.*, 2006; Baur *et al.*, 2010), and experienced international-level driver-athletes (Backman *et al.*, 2005). In contrast, three of the participants from the present study had competed at national level, three at club level, and one at regional level. The substantial differences in anthropometric measurements between our participant sample and those in other studies may be attributed to our driver-athletes' relative lack of experience and lower competitive levels, potentially resulting in lesser conditioning and physical fitness compared to other study samples.

5.3.2 Health and Lifestyle Factors

None of the seven participants reported any comorbidities or chronic lifestyle diseases. However, as mentioned previously, this does not necessarily imply that they were in good health. This is evident when examining the anthropometric measurements of the individual participants. According to the WHO guidelines, males with a waist circumference exceeding 94 cm face an elevated risk of metabolic complications, while those with a waist circumference exceeding 102 cm have a substantially increased risk. Participant six faced an elevated risk of metabolic complications, while participants three and four had a substantially increased risk for metabolic complications. Participants four and six also reported regular alcohol consumption habits.

5.3.3 Motorsport Specific Information

It is hypothesised that driver-athletes who operate open-wheel cars may exhibit better cardiovascular and physical fitness due to increased muscular strain and exposure to G-forces (McKnight *et al.*, 2019). Participant five is the only participant from the present study who competed in an open-wheeled car, while the rest all competed in closed-wheeled cars. Participants four and five also participated in the South African Endurance series. Additionally, driver-athletes participating in endurance racing may experience greater fatigue (Reid, 2022), potentially resulting in increased strength and cardiovascular fitness.

5.3.4 Physical Tests

5.3.4.1 Wall Toss Test

To assess hand-eye coordination the wall toss test was employed, which categorises performance as excellent, good, average, fair, or poor, based on the number of successful catches (Ashok, 2008). In this test, participants achieved results ranging from fair to average. These results prompt questions regarding the necessity of excellent hand-eye coordination for success in motorsport.

5.3.4.2 Foot Step Test

Lower limb coordination was assessed using the foot step test. Backman *et al.* (2005) reported that open-wheel drivers exhibited a mean of 28 ± 4 steps on the right and 26 ± 2 steps on the left. Our participant sample, however, demonstrated significantly higher scores on the foot step test compared to those reported by Backman *et al.* (2005). It is worth noting that the reliability and validity of this test has not been previously established. Consequently, we refrain from drawing definitive conclusions regarding the lower limb coordination of the present study's participants.

5.3.4.3 Reaction Time

The mean reaction time in our participant sample exhibited parity between the left and right sides. Two other studies examined reaction times in driver-athletes, although employing different tests to measure this parameter. Backman *et al.* (2005) reported a mean reaction time of 0.25 ± 0.06 seconds, while Baur *et al.* (2006) recorded a mean reaction time of 0.33 seconds for drivers. In contrast, our participants displayed a more favourable reaction time, with a mean of 0.19 ± 0.02 seconds.

5.3.4.4 Estimated VO_2 Max

We estimated the VO_2 max using the 20m shuttle run test. The estimated VO_2 max scores for our participants ranged from 26 ml/kg/min to 36 ml/kg/min. When contextualised within the treadmill-based cardiorespiratory fitness classifications by age and sex as outlined by the American College of Sports Medicine (2020), our participant sample fell within the range of very poor to fair estimated VO_2 max levels. It is noteworthy that participant five, who competed in the South African Endurance Series, exhibited the highest VO_2 max. This observation suggests that their participation in endurance racing may require a comparatively improved VO_2 max level. The relatively suboptimal estimated VO_2 max levels in our participant sample prompts further exploration regarding the necessity of robust cardiovascular fitness in the context of competitive South African motorsport.

5.3.4.5 Single-leg Heel Raise

The single-leg heel raise test was chosen due to its relevance to driving actions such as braking, clutch operation, and acceleration. Our participants demonstrated similar results for both the right and left single-leg heel raise tests. It is worth noting that while it is generally expected for individuals to achieve more repetitions on their dominant side, the present participant sample exhibited some variation in this regard, with three participants performing more heel raises on their non-dominant left side. This contrasts with the common expectation of greater strength on the dominant side.

Previous studies have suggested that achieving 25 repetitions should be considered the norm for both males and females in the heel raise test. However, Hébert-Losier *et al.* (2017) reported median values of 24 for the right side and 23 for the left side. In our study, most participants showed only a minor difference of one to three repetitions between their left and right sides, except for participant seven, who performed seven more heel raises on the right side than on the left. In general, our study sample exhibited weaker plantar flexion strength when compared to typical heel raise test values.

5.3.4.6 Grip Strength

Regarding grip strength, we reported mean values for both the left and right hands. Notably, our participant sample demonstrated higher grip strength scores on the right side, with a 3.9 kg difference between the two sides. Grip strength measurements from experienced open-wheel driver-athletes were documented in the study conducted by Raschner, Platzer and Patterson (2013). In their research, grip strength values were reported in Newtons. Upon conversion to kilograms, the mean grip strength reported was 41 kg. In comparison to the present study's findings, our participant sample exhibited a slightly superior performance in grip strength. Notably, two participants displayed higher grip strengths on their non-dominant left side, despite being right-hand dominant. Participant five particularly stood out with exceptionally high grip strength scores on both the left and right sides. This phenomenon could be attributed to the fact that this participant also competed in the South African Endurance Series, possibly suggesting that driver-athletes engaged in endurance racing may develop heightened grip strength to mitigate fatigue during prolonged steering wheel manipulation in extended racing sessions.

5.3.4.7 Neck Flexor Endurance Test

Our participants exhibited a broad spectrum of results in the neck flexor endurance test. In comparison to existing literature which suggested an average endurance time of 25 seconds for men (Domenech *et al.*, 2011; Olson *et al.*, 2006), our participants demonstrated exceptional performance, with all seven individuals surpassing the 25-second threshold in the neck flexor endurance test. Notably, participant three achieved an exceptional endurance time of 122 seconds, considerably longer than any other participant. This remarkable performance may be attributed to the fact that participant three is a professional jet pilot and aviation consultant. It is well-established that pilots are occupationally exposed to environments characterised by extremely high G-forces during flight (Tu *et al.*, 2020). It is plausible to hypothesise that the neck muscles of pilots must possess exceptional strength to withstand these high G-forces effectively.

5.3.4.8 Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST)

Results of our participant sample for the CKCUEST test showed good results when compared to results of previous studies that reported a mean of 19 touches for males (Ellenbecker, Manske and Davies, 2000) and 13 ± 5 touches for females (Lee and Kim, 2015). It can be reasoned that while driving, the upper limb is in a closed kinetic chain with the hands on the steering wheel, with lots of shaking, vibrations, and forces transferring from the car to the upper limbs and could thus result in better closed kinetic chain upper extremity stability in driver-athletes than in the general population.

An observation from our case series findings identified the relative symmetry between the left and right scores on the administered tests. This may be attributed to the inherent bilaterality of motorsport, which mandates the simultaneous engagement of both upper limbs for driving and steering, with the left hand primarily responsible for gear shifts in South African vehicles. In a similar manner, the lower extremities are actively involved, with the left limb dedicated to clutch control and the right limb tasked with both braking and acceleration.

5.4 Limitations and Recommendations for Future Research

Our research encountered several limitations that influenced the outcomes of the findings. Initially, our decision to exclusively provide the online survey questionnaire in English may have introduced selection bias by limiting participation among South African driver-athletes who preferred other languages. Another potential source of selection bias could be traced to the specific stakeholders involved in the study, potentially leading to an overrepresentation of certain circuit car racing categories in the online survey responses. As a result, our survey data did not provide a proportional representation of driver-athletes across all circuit car racing categories.

Furthermore, our decision to solely include driver-athletes competing in circuit car racing within the Western Cape region may have inadvertently excluded a significant portion of driver-athletes from other regions such as Sandton, where one of South Africa's major circuits, the Kyalami Grand Prix Circuit, is located. This restriction also omitted other forms of motorsport, and had we included a broader range of motorsport types in South Africa, it might have yielded substantially different results. Moreover, our choice to include only adult participants also imposed a limitation on our study. This decision was influenced by the requirements of the informed consent process. Consequently, our research did not gather information on adolescent driver-athletes. This may be a vulnerable group of athletes, particularly in light of reports indicating an increasing number of younger individuals engaging in competitive driving.

It is worth noting that driver-athletes are permitted to commence competitive circuit car racing from the age of 16 in South Africa. Therefore, future research should aim to address this gap by focusing on a younger cohort of driver-athletes. Research should also explore ways to develop youth programmes, scholarships, and mentorship opportunities to help young talent enter motorsport safely and progress through the ranks.

The main limitation of the present study resides in the small sample size and difficulties encountered during the recruitment process. It is noteworthy that stakeholders play an increasingly important role in the research process; however, optimal ways to involve relevant stakeholders in research remains a subject of uncertainty. Future research should assess stakeholder engagement within research activities to determine the association between the extent and quality of stakeholder engagement and research outcomes. Addressing stakeholder engagement as a scientific challenge is recommended, as proposed by Goodman and Sanders Thompson (2017) and further emphasised by Goodman *et al.* (2020).

Our findings have highlighted the importance of initiating stakeholder engagement at a more foundational level. It is apparent that a crucial starting point resides in the introduction of the concept of research to the motorsport community at its most rudimentary level. Subsequently, it is essential to implore the viewpoints regarding research from both driver-athletes and stakeholders prior to the commencement of any research processes.

While incidents of injuries and musculoskeletal problems in the context of motorsport have indeed been reported, active injury prevention strategies have not been widely adapted within the motorsport community. As researchers, we possess knowledge regarding injury prevention strategies; however, it is conceivable that this knowledge has not been effectively disseminated to the motorsport community. While motorsport has made significant strides in safety measures, there is always room for improvement. Future research should focus on practices to reduce the risk of accidents and protect the well-being of driver-athletes by starting with the education of driver-athletes on injury prevention strategies. The extent of the issue concerning motorsport-related injuries requires further exploration, with future studies employing clear definitions and standardised reporting procedures for injuries.

The practical limitations encountered in this study have led to interesting thoughts about the future direction of research in motorsport. It is imperative for motorsport to undergo a transformation aimed at a more inclusive culture. Motorsport has traditionally been a male-dominated, exclusive industry with several challenges that need to be addressed. The lack of diversity is a significant issue in motorsport. Women and individuals from diverse backgrounds have often found it difficult to be included in the industry, partly due to limited opportunities and stereotypes that portray motorsport as a male-dominant pursuit. Motorsport is an expensive sport, which makes it less accessible for individuals from lower-income backgrounds.

The high costs associated with racing, from purchasing vehicles, maintaining them, and participating in races can be a significant barrier. Future research should explore ways to attract and retain a more diverse population, breaking down barriers for individuals of all genders and backgrounds. Changing the culture of motorsport to be more inclusive may present as an ongoing challenge. Further research should provide insights into the shifts needed within the industry, focusing on education, awareness, and policies to promote inclusivity, injury prevention, and research in motorsport.

CHAPTER SIX: SUMMARY AND CONCLUSION

The aim of the present study was to describe the fitness, injury, and training profiles of South African motorsport driver-athletes. To achieve this goal, a modified research design was employed, combining a descriptive study involving the utilisation of a self-developed online survey to gather data concerning the demographic characteristics, sport-specific information, training history, and injury history of driver-athletes. Additionally, a series of physical assessments were conducted to evaluate upper limb strength, lower limb strength, reaction time, coordination, neck strength, and cardiovascular fitness within a limited group of driver-athletes and these findings have been presented as a case series. The specific objectives of this dissertation were addressed as outlined below:

1. *Describe the demographics, training history, and injury history of South African motorsport driver-athletes.*

This study's population was predominantly male (n=48, 94%) and covered a wide age range with a mean age of 45 ± 16 years. Most respondents were either employed full-time (n=21, 41%) or self-employed (n=19, 37%), and no respondents were unemployed. The main category that respondents participated in was Clubmans (n=22, 43%) and the majority of respondents currently participated at a regional level (n=21, 41%). Among respondents, 39% (n=20) were sponsored driver-athletes. The study sample had a median of 13-14 years of driving experience and on average, respondents had competed in six races in the previous 12 months. Sixty-three percent (n=32) of respondents met the WHO guidelines for physical activity for adults, with 55% (n=28) of respondents engaging in regular strength training. When investigating cardiovascular training, 57% (n=29) included this in their training regime, with only 25% (n=13) including flexibility exercises in their regular training.

When investigating training practices around a circuit outside of race days, 43% (n =22) of respondents practiced less than once a month. When examining specific exercises for motorsport, only 18% (n=9) of respondents engaged in coordination exercises, 20% (n=10) reported that they performed reaction time exercises, and a mere 24% (n=12) engaged in neck strengthening exercises. Only 35% of respondents performed warm-up exercises before a race or competition. Seventy-five percent (n=38) of respondents spent time visualising or mentally rehearsing before a race. A total of 31 injuries were reported by respondents, compromising of 10 current injuries and 21 past injuries. The area that was mostly affected was the foot/ankle (n=8, 26%) and the type of injury that was most commonly sustained was a fracture (n=9, 29%).

The most injuries were sustained during car accidents (n=13, 42%), with 62% (n=8) of injuries sustained during a car accident occurring during motorsport-specific training.

2. *Determine the cardiovascular fitness, upper body strength, lower limb strength, coordination, and reaction times of South African motorsport driver-athletes.*

A small cohort of the driver-athletes underwent a series of eight physical tests. Cardiovascular fitness was evaluated through the 20m shuttle run test, which facilitated the calculation of an estimated VO_2 max for the participants. The participant sample demonstrated a mean estimated VO_2 max of 30 ± 4 ml/kg/min. Upper body strength components were measured through the grip strength test and the CKCUEST. The mean for grip strength of participants was 54 ± 10 kg on the left side, and 58 ± 10 kg on the right side. The CKCUEST yielded a mean score of 21 ± 3 touches. Neck strength was assessed utilising the neck flexor endurance test, with the participant sample displaying a mean of 58 ± 30 seconds.

Lower limb strength, specifically plantarflexion endurance strength, was determined using the single-leg heel raise test. The case sample exhibited a mean of 20 ± 6 for the single-leg heel raise test on the right side and 18 ± 4 on the left side. Coordination assessments included hand-eye coordination using the wall toss test and lower limb coordination using the foot step test. The mean for the wall toss test was 20 ± 4 successful catches. Additionally, the means for the foot step test on both the left and right sides were 49 ± 6 touches and 54 ± 7 touches, respectively. Lastly, reaction time was evaluated via the ruler drop test, with the study sample demonstrating a mean reaction time of 0.19 ± 0.02 seconds.

This study failed to identify discernible relationships between variables such as years of driving experience, frequency of practice sessions held on circuits outside of race days, engagement in motorsport-specific exercises, training regimens, and the level of participation in motorsport. This was due to the small sample size and inability to perform statistical analyses. Moreover, the research findings did not unveil any clear relationship between the occurrence of car accidents and the age or accumulated years of driving experience among the participants. The investigation also found no compelling links between the risk of sustaining injuries and factors such as age, years of driving experience, or the specific racing category in which participants were involved. Furthermore, no relationship emerged between injury risk and the participants' engagement in physical activity or the nature of their training practices.

The absence of female participants in the case series and small sample size precluded any comparative analysis of physical fitness parameters between female and male driver-athletes. Lastly, the results demonstrated a lack of notable relationship between the level of participation and the outcomes of the physical tests administered to the participants.

In conclusion, this study has provided insights into the fitness, injury, and training characteristics of the examined cohort of driver-athletes. Our research has demonstrated that many drive-athletes do not engage in regular motorsport-specific training routines or engage in regular strength and cardiovascular training. This observation was supported by the case series, indicating that participants generally displayed poor fitness levels and physical conditioning. It is essential to highlight that these observations might not be representative of the entire population of motorsport driver-athletes nationwide. Instead, it reflects our cohort of participants, predominantly consisting of older amateur driver-athletes. The study further underscores the significance of physical fitness and conditioning as crucial components in effectively addressing the physiological and physical demands experienced by driver-athletes in motorsport.

Moving forward, future research should commence with early-stage stakeholder engagement, and researchers should actively strive to comprehend the population's perceptions of both research and the subject under investigation. Future research should focus on the development of comprehensive injury prevention protocols that are tailored to the specific disciplines within motorsport. These protocols should be designed to address the unique physical and physiological challenges associated with each motorsport discipline. Additionally, an important initial step in such research efforts would need to involve the dissemination of educational materials and information aimed at raising awareness and knowledge among driver-athletes regarding injury prevention strategies and practices. By fostering a culture of safety-consciousness, and equipping driver-athletes with the necessary knowledge and tools, the motorsport community can take proactive steps towards reducing the incidence of injuries and promoting the well-being of driver-athletes.

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APPENDICES

Appendix A: Recruitment Advertisement

Appendix B: Email to Motorsport Clubs

Dear (insert name of club chairman/secretary)

I hope you are well. I am a Masters student in Exercise and Sport Physiotherapy at the University of Cape Town and I am conducting a study to investigate and describe the demographic, fitness and training profiles of South African motorsport drivers.

Our study will include adult male and female drivers competing in circuit car racing that is situated in the Western Cape and that will be able to travel to the WP Rugby High Performance Centre for testing. This study will help to understand this unique sport and its participants in South Africa, and to provide some information on the fitness and training practices of this population of athletes.

I would like to ask for your assistance in informing the members in your club about this study and to circulate the attached recruitment advertisement to your members if possible.

Please feel free to contact me or my supervisors if you have any questions regarding the study.

Kind regards,

Christa van Eeden (Researcher)
Contact no: 071 150 3905

Supervisor: Dr. Theresa Burgess
Email: theresa.burgess@uct.ac.za

Supervisor: Mr Ken Kabongo
Email: ken.kabongo@uct.ac.za

Supervisor: Dr. Kim Buchholtz
Email: kim.buchholtz@lunex-university.net

Appendix C: HREC Approval Letter

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room 45 E-52-E-Floor- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/home/human-research-ethics

24 February 2023

HREC REF: 092/2023

A/Prof T Burgess
Division of Physiotherapy
Health & Rehab Sciences-F-45 OMB
Email: Theresa.burgess@uct.ac.za
Student:VDNCHR007@myuct.ac.za

Dear A/Prof Burgess

PROJECT TITLE: FITNESS AND TRAINING PROFILES OF SOUTH AFRICAN MOTORSPORT DRIVERS-MSC CANDIDATE-MS CHRISTA VAN EEDEN

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 28 February 2024.

Please submit a progress form, using the standardised Annual Report Form (FHS016) if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Ms Christa van Eeden will also be involved in this study.

Please quote the HREC REF 092/2023 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637. Institutional Review Board (IRB) number: IRB00001938 NHREC-registration number: REC-210208-007

HREC/ref 092.2023

Appendix D: Informed Consent Form

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
HEALTH SCIENCES

DHRS
Department of Health and Rehabilitation Sciences
FACULTY OF HEALTH SCIENCES

Divisions of Communication Sciences & Disorders • Disability Studies • Nursing & Midwifery • Occupational Therapy • Physiotherapy

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Fitness and Training Profiles of South African Motorsport Drivers

Dear participant

Thank you for considering taking part in this research. The study is being undertaken by Christa van Eeden, a Master's student in the Division of Physiotherapy at the University of Cape Town. The purpose of this study is to investigate and describe the demographic, fitness and training profiles of South African motorsport drivers.

What is the study about?

Motorsport is one of the most popular sports worldwide and a growing sport in South Africa. Despite the growing popularity of the sport, there is a lack of research on the physical demands impacting driver-athletes. The objectives of this study are to: 1) describe the demographics, training history and injury history of South African motorsport driver-athletes, 2) determine the cardiovascular fitness, upper body strength, lower limb strength, coordination and reaction times of South African motorsport driver-athletes and 3) to compare this information between adult female and male driver-athletes, and between driver-athletes competing on different levels of racing (social, club, regional and national level).

Who will be able to take part in the study?

Any adult (18 years and older) female and male motorsport driver-athlete competing on social, club, regional or national level in circuit car racing, will be able to take part in this study.

What will happen if you decide to take part in the study?

Upon completion of the informed consent form, you will be required to fill out two pre-participation questionnaires. This process aims to assess your eligibility for participation in the testing by evaluating your safety for exercise. If deemed fit for exercise, you will then proceed to engage in the physical testing.

What will happen on the day of testing?

Testing will take place at the WP Rugby High Performance Centre. COVID-19 screening protocols will be adhered to and infection prevention measures will be put in place to ensure the safety of all participants. On arrival, you will be asked to complete a questionnaire which will ask details on your demographic

information, lifestyle factors, health, level of participation, driving experience, previous injury history and training history.

Your height, body weight and waist circumference will be measured, and your body fat will be measured using skinfold calipers to pinch your skin and underlying fat at seven different sites to measure the thickness. Following these measurement procedures, you will be asked to do a warm up that consists of five minutes static cycling and a dynamic warm up routine for the upper body. The physical screening tests will then commence and consists of the following:

- **Single-leg heel raise test**: This test is used to assess the endurance of your calf muscles. You will be asked to do as many heel raises as you can on one leg. The alternate limb will be tested after a 2-minute rest.
- **Wall toss test**: This test assesses your hand-eye coordination. A tennis ball will be thrown from the right hand against the wall and you will attempt to catch it with the left hand. It is then thrown with the left hand and caught with the right. This is repeated as many times as possible in thirty seconds.
- **Grip strength**: Grip strength will be assessed using a hand dynamometer. This will involve squeezing a handle with maximum force for a duration of 3 seconds, followed by a relaxation period of 15 seconds. This sequence will be repeated twice, and subsequently, the same test will be conducted on the opposite hand.
- **Foot step test**: This test is used to measure the speed and coordination of your lower limbs. You will be asked to move your foot as fast as possible for 15 seconds between two marks while you are in a seated position. This test will be performed 2 times for each leg.
- **Neck flexor endurance test**: This will be used to test the strength of your deep neck muscles. While lying on your back, you will be instructed to chick your chin in and to lift your head approximately 2.5cm from the table. The time that you can hold the correct position is measured. The test will be repeated twice with a 2-minute rest between each testing procedure.
- **Ruler drop test**: The ruler drop test is used to assess your reaction time. While sitting with your forearm supported, you will attempt to catch a ruler as soon as possible once it is dropped. The distance at which you grab the ruler will be measured. The test will be repeated three times on each side.
- **Closed Kinetic Chain Upper Extremity Stability Test**: This test assesses the function and stability of your shoulders. In a push-up position and with your hands 91,44cm apart, you will be instructed to reach over with one hand and touch the opposite hand. You will return to the starting position and the same is then repeated with the other hand. The number of touches that you can perform in 15 seconds are counted.
- **Multistage 20m shuttle run test**: This test is used to assess cardiovascular fitness. You will run between two lines 20m apart, while keeping pace with an audio signal that increases speed with each stage. The test ends when you can no longer follow the pace.
  [Duration approximately 1h00]

<u>Do I have to take part in the study?</u>

The study is completely voluntary and you have the right to withdraw from the study at any point if you wish to do so.

Who will see the information which is collected about you during the study?

Only the researcher, Christa van Eeden, and the three supervisors will have access to the information collected from participants and during the testing procedures. No names will be used when reporting the outcomes of the study to protect the privacy and confidentiality of the participants. The findings of the study may be published in a peer-reviewed journal that may require access to an anonymised dataset, but all data will be anonymised and no personal, identifying information will be reported. In addition, all results will be presented as group-level results, so individuals will not be identifiable during any reporting.

What are the potential risks involved in taking part in the study?

There is a risk of musculoskeletal injury due to the physical tests performed. An adequate warm-up will be conducted and participants will be familiarised with all the tests to reduce the risk of injury. The researcher in this study is a qualified physiotherapist and has been trained in first aid. Should there be any injuries, she will assess the extent of the injury and refer you for further assessment and treatment if necessary.

What are the potential benefits involved in taking part in this study?

There are no direct benefits with taking part in this study. You will be given feedback on your testing results following the testing sessions. You will also receive an information pack on completion of testing containing general information on health, injury prevention as well as information regarding optimal physical conditioning.

What if something goes wrong?

The University of Cape Town (UCT) undertakes that in the event of you suffering any significant deterioration in health or well-being, or from any unexpected sensitivity or toxicity, that is caused by your participation in the study, it will provide immediate medical care. UCT has appropriate insurance cover to provide prompt payment of compensation for any trial-related injury according to the guidelines outlined by the Association of the British Pharmaceutical Industry, ABPI 1991. Broadly-speaking, the ABPI guidelines recommend that the insured company (UCT), without legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study doctor immediately of any side effects and/or injuries during the trial, whether they are research-related or other related complications.

UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while you were taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected. Copies of these guidelines are available on request.

Who do you contact if you have any questions about the study?

If you have any concerns or questions about the study, do not hesitate to contact the researcher or any of the supervisors below:

Researcher: Christa van Eeden
Contact number: 071 150 3905
Email: christavaneeden1@gmail.com

Supervisor: Dr. Kim Buchholtz
Email: kim.buchholtz@lunex-university.net

Supervisor: Dr. Theresa Burgess
Contact number: 021 406 6171
Email: theresa.burgess@uct.ac.za

Supervisor: Mr Ken Kabongo
Email: ken.kabongo@uct.ac.za

The University of Cape Town Faculty of Health Sciences Human Research Ethics Committee can be contacted if you have any ethical concerns or questions about your rights or welfare as a participant on this research study. Email: HREC-enquiries@uct.ac.za

I hereby confirm that I have read and understood all of the above information. I understand the purpose and procedures of this study. I understand the risks and benefits of the study and I know that I can contact the researcher or supervisors at any time should I have any questions or concerns about this study. I understand that I can withdraw from the study at any point without prejudice. I understand that my privacy and confidentiality will be ensured throughout the study and when reporting the outcomes of this study.

☐ I ACCEPT the above statement and give my consent to participate in the study

☐ I DO NOT ACCEPT the above statement and DO NOT give my consent to participate in the study

Participant Name and Surname: Participant Signature:

_____ _____

Date: _____

Researcher Name and Surname: Researcher Signature:

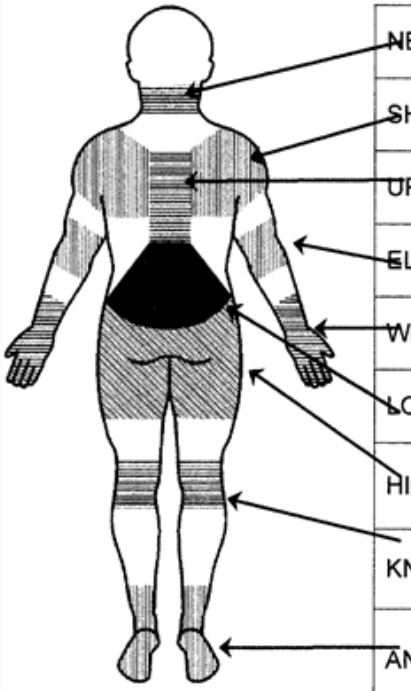
_____ _____

Date: _____

Appendix E: Nordic Musculoskeletal Questionnaire (NMQ)

MUSCULOSKELETAL DISORDERS

Please answer by putting a cross in the appropriate box_ one cross for each question. Please answer every question even if you have never had trouble in any parts of your body. This picture shows how the body has been divided. You should decide for yourself which part (if any) is or has been affected.



	Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	During the last 12 months have you been prevented from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble in:	During the last 12 months have you seen a physician for this condition:	During the last 7 days have you had trouble in:
NECK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
SHOULDERS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
UPPER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ELBOWS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
WRISTS/ HANDS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
LOWER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
HIPS/ THIGHS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
KNEES	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ANKLES/ FEET	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

Appendix F: Physical Activity Readiness Questionnaire (PAR-Q+)

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or **NO.**	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. **Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact

www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

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Appendix G: Self-developed Questionnaire

Demographic, Training History and Injury Questionnaire

SECTION 1: GENERAL INFORMATION

1. Name and Surname: _____
2. Date of birth: _____
3. What is your gender?
   ☐Male ☐Female ☐Prefer not to say
4. What is your employment status?
   ☐Student ☐Unemployed ☐Full-time ☐Part-time ☐Self-employed ☐Retired
5. What is your occupation? _____

SECTION 2: CIRCUIT CAR RACING

1. What is the main category of circuit car racing that you participate in?
   ☐Clubmans ☐ Classic cars ☐ Fine cars ☐Formula Libre ☐Gti Challenge ☐V8 Master Series
   ☐Sports & GT Cars ☐Supercars ☐Thunder Saloons Other: _____
2. What class in your category do you participate in? _____
3. What type of car do you race with? _____
4. If you participate in a second category, please specify: _____
5. Please specify on what level you participated in the years mentioned below:
   Current level: ☐Social ☐Club ☐Regional ☐National ☐International ☐Did not participate
   2022: ☐Social ☐Club ☐Regional ☐National ☐International ☐Did not participate
   2021: ☐Social ☐Club ☐Regional ☐National ☐International ☐Did not participate
   2020: ☐Social ☐Club ☐Regional ☐National ☐International ☐Did not participate
   2019: ☐Social ☐Club ☐Regional ☐National ☐International ☐Did not participate
6. What is the highest level of participation of your racing career?
   ☐Social ☐Club ☐Regional ☐National ☐International
7. Are you sponsored? ☐Yes ☐No
8. For how many years have you been racing?
   ☐1-2 years ☐3-4 years ☐5-6 years ☐7-8 years ☐9-10 years ☐11-12 years ☐13-14 years
   ☐15-16 years ☐17-18 years ☐19-20 years ☐More than 20 years
9. How many races have you completed in the past 12 months? _____
10. Have you been involved in any car crashes/accidents in the past 12 months? ☐Yes ☐No

11. Are you aware of any concussion protocols to follow when sustaining a concussion in a car crash? ☐Yes ☐No

12. On average, in a calendar month, how often do you practice on a circuit excluding race/competition days?
    ☐Less than once a month ☐Once a month ☐Every third week ☐Every second week ☐Every week ☐Other

13. On average, in a week, how often do you practice on a circuit excluding race/competition days?
    ☐I do not practice weekly ☐Once a week ☐Twice a week ☐Three days a week
    ☐Four days a week ☐Five days a week ☐More than five days a week

14. How long are your average practice sessions on a circuit?
    ☐Less than 30 minutes ☐30-45 minutes ☐46-60 minutes ☐61-90 minutes
    ☐91-120 minutes ☐More than two hours

15. How many laps on average do you complete in a practice session? _____

16. Do you use any racing simulator software for training? ☐Yes ☐No

17. Do you do any coordination exercises? (For example, hand-eye coordination skills, jumping rope, juggling etc.) ☐Yes ☐No ☐Unsure

18. Do you do any reaction time exercises? (For example, drop and catch exercises, ball dropping etc.) ☐Yes ☐No ☐Unsure

19. Do you do any neck strengthening exercises? ☐Yes ☐No ☐Unsure

20. Do you do any warm-up before going out onto the circuit to race? ☐Yes ☐No ☐Unsure

21. Do you do any stretches or mobility exercises before going out onto the circuit to race? ☐Yes ☐No ☐Unsure

22. Do you spend any time visualizing or mentally rehearsing before a race? ☐Yes ☐No ☐Unsure

23. Do you use any cooling strategies before, during or after a race to deal with heat and increased temperatures in the car? (e.g. cooling packs, cooling vests, ingestion of cold water or ice, cold air exposure etc.) ☐Yes ☐No ☐Unsure

24. If you use cooling strategies, please specify: _____

SECTION 3: HEALTH AND LIFESTYLE FACTORS

1. Do you suffer from any of the following?

   Diabetes: ☐Yes ☐No ☐Unsure

   High blood pressure: ☐Yes ☐No ☐Unsure

   High cholesterol: ☐Yes ☐No ☐Unsure

   Pulmonary disorders, asthma, COPD: ☐Yes ☐No ☐Unsure

Cardiac or heart problems: ☐Yes ☐No ☐Unsure

Thyroid problems: ☐Yes ☐No ☐Unsure

Cancer: ☐Yes ☐No ☐Unsure

Epilepsy: ☐Yes ☐No ☐Unsure

HIV/Aids: ☐Yes ☐No ☐Unsure

Rheumatoid arthritis: ☐Yes ☐No ☐Unsure

2. Do you smoke? ☐Yes ☐No

3. If you smoke, how many cigarettes do you smoke on average in a day? _____

4. How often do you consume alcohol?

   ☐Never/I don't drink ☐Less than once a week ☐1-2 times a week ☐3-4 times a week ☐5-6 times a week ☐Unsure

5. Do you consider yourself eating a healthy and balanced diet? ☐Yes ☐No ☐Unsure

6. On average, how many hours of sleep do you get in a night?
   ☐Less than 4 hours ☐4-5 hours ☐5-6 hour ☐More than 6 hours

7. Please indicate the quality of your sleep by choosing the correct number on the following scale: (1= Poorly: disrupted sleep 4= Average: slept fairly well 7= Restful: sounds sleep)
   1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐

SECTION 4: PHYSICAL ACTIVITY AND EXERCISE INFORMATION

1. Do you participate in at least 150-300 minutes of moderate-intensity, or 75-150 minutes of vigorous-intensity physical activity per week? ☐Yes ☐No ☐Unsure

2. Do you participate in any of the following types of physical activity?

Strength training: ☐Yes ☐No ☐Unsure

Cardiovascular training: ☐Yes ☐No ☐Unsure

Flexibility exercises or yoga: ☐Yes ☐No ☐Unsure

Pilates: ☐Yes ☐No ☐Unsure

CrossFit: ☐Yes ☐No ☐Unsure

3. Do you do any other training? If yes, please specify: _____

4. Do you participate in any other sports? ☐Yes ☐No

5. If you participate in any other sports, please specify: _____

SECTION 5: INJURY HISTORY

Please provide the details of all injuries sustained in the past 12 months which inhibited you from training, competing or being physically active irrespective as to whether you sought medical attention or not.

An injury is defined as tissue damage or other derangement of normal physical function.

Do you have any current injuries?

(Current injury - currently suffering from an injury or an injury sustained in the past three months)

☐Yes - Continue to next section

☐No - Go to section 10 (SECTION 5:INJURY HISTORY)

Current injury 1: Please answer all the questions below for current injury 1.

1. Please indicate the body part that was affected:
   ☐Head ☐Neck ☐Shoulder ☐Upper arm ☐Elbow ☐Forearm ☐Wrist/hand ☐Chest/trunk ☐Ribs/thorax ☐Upper back ☐Lower back ☐Pelvis ☐Hip ☐Thigh/upper leg ☐Knee ☐Lower leg ☐Foot/ankle ☐Other

2. Please indicate the type of injury sustained:
   ☐Bruise/contusion ☐Concussion ☐Whiplash ☐Dislocation/subluxation ☐Fracture ☐Ligament injury ☐Inflammation/swelling ☐Muscle injury ☐Tendon injury ☐Nerve injury ☐Unsure

3. What was the cause of the injury?
   ☐Car accident ☐Acute/sudden onset ☐Chronic/overuse injury

4. Please specify the type of activity at the time of injury:
   ☐Competition ☐Motorsport specific training ☐Other physical activity/exercise ☐Other

5. Please specify what type of treatment you received for the injury: (More than one treatment can be selected)
   ☐No treatment ☐Self treated ☐Physiotherapist ☐Doctor ☐Chiropractor ☐Biokineticist ☐Surgery ☐Medication ☐Other

6. Please specify the number of days that you were unavailable for training or competition due to injury:
   ☐0 days ☐1-7 days ☐8-28 days ☐More than 28 days

Do you have another current injury?

☐Yes - Continue to next section

☐No - Go to section 10 (SECTION 5:INJURY HISTORY)

Do you have any past injuries?

(Past injury - injury sustained four or more months ago)

☐Yes - Continue to next section

☐No - Go to section 14 (THANK YOU FOR..)

Past injury 1: Please answer all the questions below for past injury 1.

7. Please indicate the body part that was affected:
   ☐Head ☐Neck ☐Shoulder ☐Upper arm ☐Elbow ☐Forearm ☐Wrist/hand ☐Chest/trunk ☐Ribs/thorax ☐Upper back ☐Lower back ☐Pelvis ☐Hip ☐Thigh/upper leg ☐Knee ☐Lower leg ☐Foot/ankle ☐Other

8. Please indicate the type of injury sustained:
   ☐Bruise/contusion ☐Concussion ☐Whiplash ☐Dislocation/subluxation ☐Fracture ☐Ligament injury ☐Inflammation/swelling ☐Muscle injury ☐Tendon injury ☐Nerve injury ☐Unsure

9. What was the cause of the injury?
   ☐Car accident ☐Acute/sudden onset ☐Chronic/overuse injury

10. Please specify the type of activity at the time of injury:
    ☐Competition ☐Motorsport specific training ☐Other physical activity/exercise ☐Other

11. Please specify what type of treatment you received for the injury: (More than one treatment can be selected)
    ☐No treatment ☐Self treated ☐Physiotherapist ☐Doctor ☐Chiropractor ☐Biokineticist ☐Surgery ☐Medication ☐Other

12. Please specify the number of days that you were unavailable for training or competition due to injury: ☐0 days ☐1-7 days ☐8-28 days ☐More than 28 days

Do you have another past injury?

(Past injury - injury sustained four or more months ago)

☐Yes - Continue to next section

☐No - Go to section 14 (THANK YOU FOR..)

END OF QUESTIONNAIRE

Thank you for taking the time to complete the questionnaire

Appendix H: Borg Scale

Borg Scale: Rate of Perceived Exertion

Rating	Descriptor
6	-
7	Very, very light (rest)
8	-
9	Very light (gentle walking)
10	-
11	Fairly light
12	-
13	Somewhat hard (steady pace)
14	-
15	Hard
16	-
17	Very hard
18	-
19	Very, very hard
20	Exhaustion