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An investigation of the physiological demands and physical preparation strategies of jockeys and the development of a standardised sport specific physical fitness assessment protocol for the horse racing industry

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Declaration

I declare that the work in this thesis is my own work, and was completed under the supervision of Dr Sarah Jane Cullen (of the Department of Sport and Exercise Science, Waterford institute of Technology), Dr Giles Warrington (of the Department of Physical Education and Sport Sciences, University of Limerick) and Dr Adrian McGoldrick (of the Irish Horse Racing Regulatory Body). This work has not been submitted for any academic award at this, or any other, third level institution.

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Abstract

Despite the international popularity of horse racing, limited information exists on the relative physical demands of flat national hunt (NH) racing or the typical physical preparation strategies used by jockey's in preparation for horse racing. The thesis aimed to investigate race demands and preparation strategies of professional jockeys whilst also developing a standardised physical fitness testing battery for the horse racing industry.

Chapter Three reviews physiological monitoring tools for individual sport athletes. Chapter Four explored the physical preparation strategies for racing in 85 professional jockeys using a specifically designed questionnaire. A physiological inventory was designed for Chapter Five to monitor the absolute and relative responses of 20 jockeys over short and long race distances for flat (short: 1,247.2 ± 184.7 m; long: 2,313.4 ± 142.2 m) and NH (short: 3,480.2 ± 355.3 m; long: 4,546.4 ± 194.3 m) racing while Chapter Six sought to explore the design and test-retest reliability of the Jockey-Fit Testing Battery in a cohort of 20 trainee jockeys.

The results of Chapter Three revealed the monitoring of heart rate (HR) and blood lactate concentration to be valid and reliable parameters to assess the physiological demands of individual athlete sports. The findings of Chapter Four revealed that jockeys work a large number of hours (34 ± 14) in addition to completing multiple races per week (6.9 ± 6.4). There are low participation rates in strength and conditioning (S&C) (42%) and only 33% of jockeys surveyed utilise high intensity training. Chapter Five discovered that horse racing is a physically demanding sport with peak blood lactate concentration reported as maximal (≥8 $mmol{\cdot}l^{-1}$) across 3 race types (long NH race, short flat race and long flat race). Mean HR in the long flat race (151 ± 19 $b{\cdot}min^{-1}$) was significantly lower than the mean HR reported in the short flat race (short: 171 ± 15 $b{\cdot}min^{-1}$) and NH races (short: 181 ± 8 $b{\cdot}min^{-1}$; long: 182 ± 9 $b{\cdot}min^{-1}$) (p=0.000, ES=0.469). Chapter Six provided a valid and reliable fitness testing battery for jockeys.

This thesis is the first to present and analyse the physical preparation strategies of Irish jockeys. The present thesis reinforces and extends previous research which suggests that horse racing is a physiologically demanding sport while providing novel data over multiple distances in both flat and NH racing. While jockeys do not appear to meet the high intensity nature of competitive racing while riding out, the Jockey-Fit Testing Battery represents a feasible and scientifically rigorous platform to monitor jockey fitness, assess fitness interventions, and provide normative performance data for the horse racing industry. Further research is needed to assess the implementation of S&C strategies using the Jockey-Fit Testing Battery on performance and injury.

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"Sixty years ago I knew everything; now I know nothing; education is a progressive discovery of our own ignorance."

Will Durant

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List of Publications

Peer Reviewed Publications (included as part of the thesis)

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2019). Physiological and Performance Monitoring in Competitive Sporting Environments: A Review for Elite Individual Sports. *Strength & Conditioning Journal*, *41*(6), 62-74.

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2020). Physical Preparation Strategies of Professional Jockeys. *The Journal of Strength and Conditioning Research* (Published ahead of print DOI: 10.1519/JSC. 0000000000003514).

Kiely, M., Warrington, G., McGoldrick, A., Pugh, J and Cullen, S. (2020). The physiological demands of professional flat and jump horseracing. *The Journal of Strength and Conditioning Research* (Published ahead of print DOI: 10.1519/JSC.0000000000003677).

Additional Peer Reviewed Publications

This does not form a chapter in the thesis as the data was not collected by the participant

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Conference Proceedings

Kiely, M., Warrington, G., McGoldrick, A and Cullen, S. (May 2019). The physiological demands of short and long race distances in national hunt racing. *All Ireland Postgraduate Conference,* Athlone, Ireland.

Kiely, M., Warrington, G., McGoldrick, A and Cullen, S. (July 2019). The physiological demands of national hunt racing on professional jockeys. *European Conference of Sports Science,* Prague, Czech Republic.

Kiely, M., Warrington, G., McGoldrick, A., Pugh, J and Cullen, S. (November 2019). The physiological demands of racing on professional jockeys. *International Conference for Health Safety and Welfare of Jockeys,* Dubai, United Arab Emirates.

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List of Abbreviations

ACSM	American College of Sport Medicine
ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
BMI	Body Mass Index
CI	Confidence Interval
CMJ	Counter Movement Jump
DXA	Dual energy X-ray absorptiometry
EE	Energy Expenditure
EMG	Electromyography (EMG)
ES	Effect size
GPS	Global Positioning System
HIIT	High Intensity Interval Training
HR	Heart rate
HR_{peak}	Peak heart rate
HRI	Horse Racing Ireland
ICC	Intraclass correlation
IgA	Immuno-globulin A
IHRB	Irish Horse Racing Regulatory Body
NH	National Hunt
NCCA	National Collegiate Athletic Association
NSCA	National Strength & Conditioning Association
RACE	Racing Academy and Centre of Education
RPE	Rating of perceived exertion
SD	Standard deviation
SE	Standard error
SEM	Standard error of measurement
SPSS	Statistical Package for the Social Sciences
sRPE	Session rate of perceived exertion
S&C	Strength and conditioning
VAT	Value added tax

$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
$\dot{V}O_{2\ max}$	Maximum oxygen uptake
USG	Urine specific gravity

Units of Measurement

$b{\cdot}min^{-1}$	Beats per minute
Cm	Centimetre
ºC	Degree Celsius
$g{\cdot}ml^{-1}$	Grams per millilitre
Hz	Hertz
Kcal	Kilocalorie
Kg	Kilogram
Km	Kilometre
Km/hr	Kilometres per hour
lbs	Pounds
m	Metre
METS	Metabolic equivalent
ml	Millilitre
$ml{\cdot}kg^{-1}{\cdot}min^{-1}$	Millilitre per kilogram per minute
$mmol{\cdot}L^{-1}$	Millimole per litre
MMP	Mean minute power
ng/ml	Nanograms per millilitre
s	Second

Glossary of Terms

Amateur jockey: An amateur jockey does not receive a riding fee when participating in professional races with most amateurs working as full time stable staff. Amateur jockeys predominantly ride in point to point racing.

Apprentice jockey: A flat jockey who has not yet fully qualified by riding a set quota of race wins. Apprentice jockeys receive a weight allowance, also sometimes known as a claim to account for their lack of experience when racing against fully professional jockeys.

Conditional jockey: A national hunt jockey who has not yet fully qualified by riding a set quota of race wins. Conditional jockeys receive a weight allowance, also sometimes known as a claim to account for their lack of experience when racing against fully professional jockeys.

Delphi Method: A questionnaire validation method where opinion is gathered from a group of experts over one or two iterative rounds of questioning and justification of answers.

Flat racing: Racing over a course distance of 1-4km where no obstacles are present. Jockeys are permitted to carry an allocated weight of 52.7-64kg dependant on their experience and/or the horse they ride.

Going: The underfoot conditions at a race track.

Keen horse: A horse that wants to run forward with increasing speed in a race at a time that is undesirable to do so.

Making weight: The practice of achieving a desired body mass for an athlete to compete in a certain weight category within a sport.

National hunt racing: Also known as jump racing; Racing over a course distance of 3.2-7.2km where hurdles or fences are present to jump, Jockeys are permitted to carry an allocated weight of 62-76kg dependant on their experience and/or the horse they ride.

Professional jockey: A professional jockey receives a set fee for riding in each race and can claim a percentage of the prize money.

Quasi-isometric effect: Metabolic reaction to increase blood flow in areas of increased muscular pressure which may increase heart rate.

Riding out: A non-racing activity sometimes referred to as 'riding out'. Jockeys ride a horse to train it in preparation for a race. The jockey will typically get the horse to spend time in each riding gait. These consist of walk, trot, canter and gallop with an increase in velocity expected during each respective riding gait.

Riding Gait: Form of locomotion identified by the patterns of a horse's legs.

Schooling: A non-racing racing activity. Jockeys ride a horse over small obstacles to train it in preparation for a national hunt race.

Tack: Tack is equipment or accessories equipped on horses.

Trainee jockey: A trainee jockey is 16 years or older and attends the Racing Academy and Centre of Education in Co. Kildare to complete a foundational course in becoming a jockey before applying for an amateur or professional licence.

Velocity: Speed in a given direction.

Chapter One: Introduction

1.1 Background

Horse racing is a hugely popular sporting, cultural and social endeavour in Ireland. In fact, it is second only to the GAA in terms of Irish sporting attendances and contributes an estimated €1.84 billion annually to the Irish economy (Deloitte, 2017). Currently, in Ireland, 146 professional jockey licenses are held by flat and national hunt (NH) jockeys with NH jockeys also known as jump jockeys, with a further 298 qualified (amateur) riders registered (IHRB and Irish National Hunt Steeplechase Committee, 2019). Jockeys must chronically maintain a low body mass to obtain stipulated racing weights while also maintaining sufficient physical conditioning to participate in multiple races per day, several days each week (Cullen et al., 2015). Previous research has identified jockeys as a population with low energy availability (Dolan et al., 2011), poor bone health (Warrington et al., 2009), high occurrence of injury (O'Connor, Warrington, McGoldrick, & Cullen, 2017) and a high prevalence of depressive symptoms (Losty et al., 2019), however little is known in relation to training, the relative physiological demands of professional racing in relation to distance or indeed athletic ability. This investigative research proposes the first study of its kind to identify jockey's physical preparation strategies, evaluate the physiological demands of races with respect to race distance while also providing a novel and reliable fitness testing Battery for the horse racing industry. A knowledge of competitive racing demands would allow practitioners establish appropriate strength and conditioning practices for jockeys to prepare for and perform optimally in competitive races. For this body of work, 'competition demands' refers to the demands experienced by jockeys in professional flat or professional jump racing while excluding riding work and point to point amateur races.

Strength and conditioning (S&C) and physical preparation strategies have been studied extensively in professional team sports such as American football (Ebben & Blackard, 2001) and Rugby (Weakley et al., 2017) in addition to a multitude of individual sports including swimming (Crowley, Harrison, & Lyons, 2018); tennis (Reid & Schneiker, 2008); rowing (Gee, Olsen, Berger, Golby, & Thompson, 2011) and cycling (Yamamoto et al., 2010). S&C can be defined as "the specialist area encompassing the physical preparation of athletes for performance in sport, while aiming to prevent or minimise the risk of injury" (UKSCA, 2020). S&C is linked with a reduction in the incidence of injury (Case, Knudson, & Downey, 2020; Hitchens et al., 2010) and is associated with improvements in performance in aerobic capacity, time trial performance and maximal power (Yamamoto et al., 2010). Additionally, combined aerobic and resistance training has been shown to repeatedly improved measures of strength and endurance (Kubukeli, Noakes & Dennis, 2002). Previous training strategies and associations with riding performance has not been documented in the literature.

Unfortunately, little research exists in relation to S&C in jockeys, and whether this population are optimally prepared for the demands of their sport. Furthermore, without a physical testing battery it is not known if S&C practices would have a positive correlation on a jockey's performance. It has previously been established that 'riding out', a practice commonly engaged in amongst jockeys as part of their training, which frequently involves walking, trotting and cantering in horse racing yards does not meet the previously reported intensities of race riding (Kiely et al., 2019a). Likewise, it is not known whether jockeys participate in additional physical preparation to meet the specific demands of racing. Hypothetically, an optimal level of physical preparation would likely have a positive influence on riding performance and the ability to recover between rides, yet this association has not been proven. Evidence does suggests low levels of aerobic and anaerobic fitness are associated with a greater risk of falls and associated injury (Hitchens, Blizzard, Jones, Day, & Fell, 2011). Moreover, with no specified off-season in the congested horse racing calendar (Wilson, Hill, Martin, Morton, & Close, 2020), jockeys must be capable of competing all year round.

Horse racing has been described as a sport where jockeys need to be aerobically and anaerobically fit (Cullen et al., 2015; Trowbridge et al., 1995). Currently, only three research studies exist in the scientific literature investigating the physiological demands of racing, each with limitations in how the relative intensity and physical demands of races were assessed. While mean and peak heart rate (HR) have been reported in both flat and NH racing (Cullen et al., 2015; O'Reilly, Cheng, & Poon, 2017; Trowbridge et al., 1995), data were not presented relative to race distance which varies considerably (1 to 7.2 km) depending on the race type. Additionally, blood lactate concentration, a metabolic indicator of exercise intensity, has only been reported in NH racing (Trowbridge et al., 1995). The ability of the body to maintain optimal physiological function is based on both the availability of energy sources and competing physiological systems. The use of energy sources such as carbohydrates, fats or proteins are proportionately dependant on the intensity and duration of physical efforts (Stanfield, Germann, Niles, & Cannon, 2011). It is therefore imperative that the physiological demands of racing are reported relative to distance and duration. This information would enable practitioners to compare flat and NH races and design specific training interventions to target the relevant intensity and energy systems utilised during race riding. In turn, this would supplement riding related work which is understood not to prepare jockeys for the high intensity demands of racing (Kiely et al., 2019a).

While there is a paucity of knowledge surrounding the physical preparation strategies of jockeys and the relative demands of flat and NH racing, there is also no validated or reliable physical fitness testing battery for jockeys. A reliable physical fitness testing battery provides practitioners an opportunity to implement evidence based physical preparation (Welk, 2017) which is a prerequisite across most sporting professions. A protocol that allows practitioners to monitor and assess jockey performance can provide the industry with normative fitness data on a national and international level and provide a basis to assess future training interventions. A comprehensive understanding of jockey's physical preparation strategies, the specific intensity demands of racing in addition to the formation of a reliable fitness testing battery will enable practitioners to design, implement and assess training based interventions for jockey athletes for the optimisation of performance.

1.2 Thesis aim

The aim of this research was to investigate the specific race demands and preparation strategies of professional jockeys as well as developing a physical testing battery for the horse racing industry.

1.3 Thesis objectives

(i) To conduct a review of physiological monitoring tools that can be applied in a competitive and individual sporting environment (Study One, Chapter Three).

(ii) To investigate the current physical preparation strategies of jockeys (Study Two, Chapter Four).

(iii) To examine the physiological demands of flat and NH jockeys during competitive racing over short and long races (Study Three, Chapter Five).

(iv) To develop a valid sport specific physical fitness assessment battery for jockeys (Study Four, Chapter Six).

(v) To investigate the test-retest reliability of the physical fitness assessment battery with trainee jockeys from RACE academy (Study Four, Chapter Six).

1.4 Thesis structure

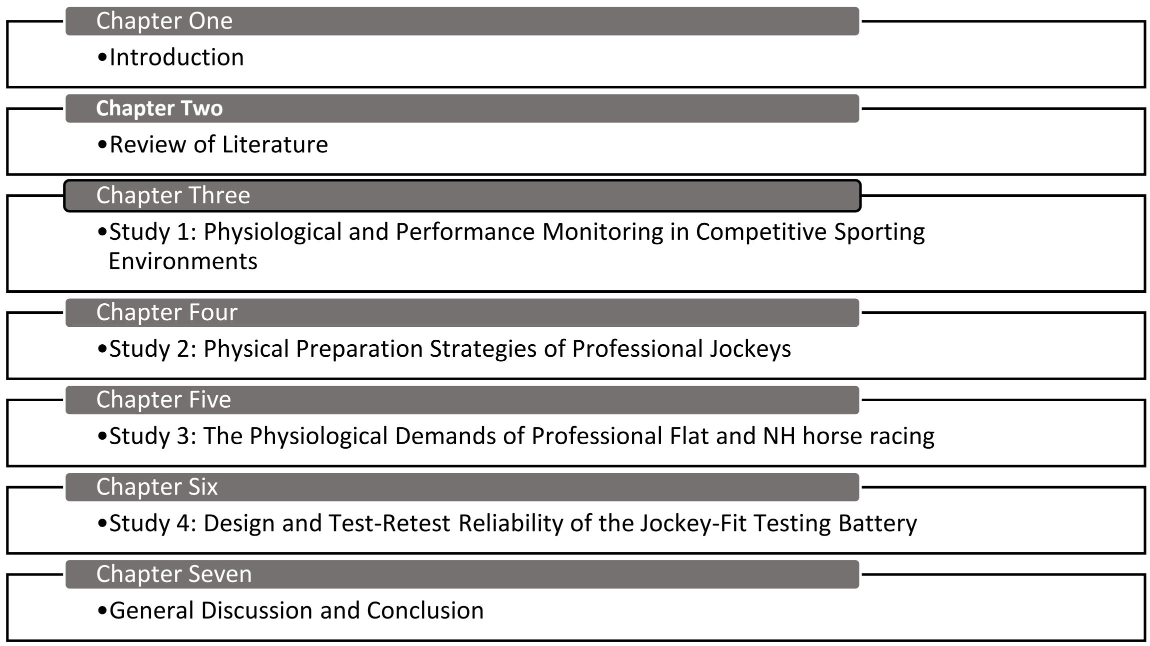

Figure 1.1 Schematic overview of the thesis structure.

A schematic overview of the thesis can be seen in figure 1.1. The current chapter delivers a brief introduction highlighting the background, aim, and objectives of the research in addition to brief explanations and definitions of key terms within the research. Chapter Two provides a critical synthesis of the available literature indicative of the thesis aim. Initially, the review of literature provides a summary of the physiological demands of racing and the current physical preparation strategies of professional jockeys. The literature in this chapter provides a basis to interpret the findings in each empirical chapter.

Chapter Three presents a narrative review of literature on the reliability and validity of physiological monitoring tools appropriate for monitoring individual sport athletes. While Chapter Two provided a general overview of horse racing and the environmental demands placed on the jockey, Chapter Three identifies physical testing assessments and protocols that can be applied by practitioners in a horse racing environment. The scientifically rigorous methods identified were considered for use for the physical data collection in the empirical chapters with particular reference to Chapter Five.

Chapter Four, Five and Six contain empirical research and are presented in the format of a journal article. A dearth of information in relation to training and S&C practices was identified in the review of literature. Chapter Four provides an insight into the physical preparatory strategies of jockeys while specifically investigating the background information of jockeys, associated exercise habits with making weight and jockeys current practices and perceptions of Strength & Conditioning (S&C).

While it was hypothesised that jockeys do not prepare to meet the demands of racing, no physiological data was available for practitioners relative to race distance from both flat and jump jockeys. Chapter Five investigates the physiological demands of flat and NH racing and presents relative data concerning race distance for flat and NH jockeys. The objectives of Chapter Four and Five are closely linked with an identification of the physical preparation strategies of jockeys and secondly, research to establish whether jockeys physical preparation is sufficient to meet the identified physiological demands of racing in Chapter Five.

Chapter Six contains a test-retest reliability analysis of a physical assessment testing battery for jockeys. Physical fitness tests were appraised for test-retest reliability analysis based on the physical demands of horse racing identified in the review of literature in Chapter Two and the physiological demands of horse racing identified in Chapter Five.

Chapter Seven includes an in-depth discussion of the research presented in the thesis and concludes the thesis findings from each empirical chapter. Future research directions are presented in addition to practical applications of the research findings from Chapter Three to Chapter Six. Published chapters have undergone minor formatting and structural changes to aid the overall presentation and alignment of this thesis. The published articles and journal of publication, research impact factor and quartile can be found in the appendices as directed by table 1.1.

Table 1.1 Journal of Publication, ISI impact factor and quartile for each chapter presented in the thesis

Chapter	Journal	Impact Factor	Quartile
3 **Full article can be viewed in Appendix G*	The Strength and Conditioning Journal	0.986	4
4 *Full article can be viewed in Appendix H*	The Journal of Strength and Conditioning Research	3.017	1
5 *Full article can be viewed in Appendix*	The Journal of Strength and Conditioning Research	3.017	1
Appendix J	The Journal of Sports medicine and Physical Fitness	1.302	2

Chapter Two: Review of Literature

2.1 Preface

This chapter provides an overview of the existing literature while providing a framework for the thesis based on identified gaps in the available research. A brief introduction to horse racing in Ireland is followed by a description of the complex lifestyle of a Jockey. The physiological demands of racing and associated equine sports are reviewed and subsequently physiological monitoring tools to evaluate these demands are presented. The chapter concludes with an investigation into fitness testing with a specific focus on the formation, validity and reliability of a fitness testing battery. The rationale for conducting this research study, as detailed in Chapter One, is well supported by the review of literature which also serves to guide and provide a framework for the research and content of subsequent chapters.

2.2 Introduction to Irish horse racing

Today, horse racing has become a major professional sport in Ireland and around the world. There were 363 race meetings at 26 Irish racecourses across 2019, with total prize money of over 66 million euro. A reported 1.3 million people were in attendance at Irish racecourses (Horse Racing Ireland, 2019) with only the Gaelic Athletic Association in Ireland attracting more attendees than horse racing per annum (Deloitte, 2017). Financially, Irish horse racing contributes substantially to the Irish exchequer with breeding, horse ownership, government betting taxes, racing and off course expenditure by race attendees estimated to generate a total of €914 million while secondary business from these core stakeholders produces approximately €927 million (Deloitte, 2017). A byproduct of successful racing means Ireland is second only to the United States in bloodstock sales with €438 million worth of sales by Irish vendors. Before 1969, Irish breeding was amateur in approach, however Ireland is now a world leader in bloodstock, renowned for both their quality and quantity in the breeding industry producing nearly half of all thoroughbreds in Europe yearly (Deloitte, 2017).

Professional horse racing in Ireland consists of Flat racing and NH racing, also known as jump racing. Flat racing ranges from 1 km to 4.4 km and NH courses range from 3.2 km up to 7.2 km involving several obstacles. Although there is no established off-season, aided by the introduction of floodlit all-weather tracks (Wilson, Drust, Morton, & Close, 2014), flat racing predominantly occurs from March to November with NH racing typically taking place between November and March (Dolan et al., 2011).

In 2019 there were 8,949 horses in training in Ireland with 3,246 stable staff which has increased each year since 2015 (Horse Racing Ireland, 2019). Horses in flat racing can begin their racing career at two years old while Horse Racing Ireland directives (Horse Racing Ireland, 2020) ensure no NH horses are permitted to jump obstacles until they are four years old. While Irish horses and jockeys had large scale success at home last year, they also had success in the UK and internationally winning €15,353,171 and €9,271,549 respectively (Horse Racing Ireland, 2019).

2.3 The jockey

2.3.1 Racing and licensing

Horse racing is a gender equal professional sport in which males and females compete against each under the same rules (Gruender, 2007). Jockeys in professional horse racing are universally classified as flat jockeys or NH jockeys. In 2019 there were a total of 107 flat and 117 NH jockeys (Horse Racing Ireland, 2019). A total of 2,663 races were run in Ireland in 2019 providing jockeys with a total of 31,505 potential rides (Horse Racing Ireland, 2019). Jockeys earn money from racing or from trainers by 'riding ' or schooling over fences however financial security is attained only by a minority of jockeys who face constant pressure to make weight under specific licensing regulations (Gruender, 2007).

Flat jockeys earn €172.36 per ride while NH jockeys have a riding fee of €197.04 per ride before tax (Horse Racing Ireland, 2020). Additionally, jockeys can win approximately 6% of the race prize fund if successful. Minor deductions from these fees include VAT and contribution to pensions and funds for injury support organisations, for jockeys who do not have the capacity to work. A professional racing license can be gained at 16 years of age or thereafter (Horse Racing Ireland, 2020). While the Irish Racing Academy and Centre of Education (RACE) is in Co. Kildare, jockeys are not required to attend a racing school to obtain a jockey license. It is however required that on application for a license that individuals complete a two-day riding induction course following their sixteenth birthday in addition to gaining experience as a rider in racing yards. Following the completion of a medical and concussion screening, an interview then takes place with the Irish Horse Racing Regulatory Board (IHRB) and Irish National Hunt Steeplechase Committee.

2.3.2 Weight allocations and weight making strategies

Horse racing is a weight-regulated sport. Weight classifications are based on the horse's form in previous races with better horses receiving a heavier weight allocation. This handicap system aims to improve the competitiveness of the sport. Weight classifications for jockeys competing in flat racing range from 52.7 to 64kg while NH racing weights range from 62-76kg (Horse Racing Ireland, 2020). Jockeys must align their riding weight which is inclusive of the saddle, protective gear and clothing with the weight allocation of their horse (Cullen et al., 2015). Less experienced flat and NH jockeys known as apprentice and conditional jockeys respectively may ride at a lower body weight depending on their "claim". A claim is a weight allowance permitted to inexperienced jockeys which ensures a competitive race and encourages trainers to hire the more inexperienced jockey. Beginning at 4.5kg (10lbs) for apprentices and 3.2kg (7lb) for conditionals, the claim reduces gradually after a set number of race wins for each jockey license. Once a conditional jockey has 50 race wins and an apprentice has 95 race wins, no weight claim is received and a jockey must carry the horses' full allocated weight (IHRB and Irish National Hunt Steeplechase Committee, 2019).

Unique to horse racing is the necessity for jockeys to maintain weight on a daily basis unlike other weight category sports (Wilson, Drust, et al., 2014a). Jockeys must weigh out for each race, often competing at different weights on the same day and additionally they must weigh in if they finish in the first five race positions. Partially due to the introduction all-weather racing facilities, jockeys must now ensure they maintain weight all year round (Wilson et al., 2014a). On attainment of a professional license, jockeys place in the lowest decile (5% for males and 10% females) per population in international weight-for-age scales (Greene, Naughton, Jander, & Cullen, 2013). Weight management strategies are varied; jockeys are principally reliant and influenced by past cultural practices which may not be grounded in scientific rationale (Martin, Wilson, Morton, Close, & Murphy, 2017; Warrington et al., 2009; Wilson et al., 2014a). It is well documented that both acute and chronic fasting and dehydration techniques are utilised by jockeys to make race specific weights (Dolan et al., 2011; Martin et al., 2017; Warrington et al., 2009; Wilson, 2020). Acute strategies employed by jockeys include thermal dehydration with both saunas and sweat suits in addition to abnormal eating strategies including self-induced vomiting known as “flipping” (Dolan et al., 2011; Labadarios, Kotze, Momberg, & Kotze, 1993; Leydon & Wall, 2002) with jockeys frequently reporting a loss of up to 4% of body mass in 48 hours prior to racing (Dolan et al., 2013). Chronic weight regulation strategies typically used by jockeys include prolonged periods of an energy deficient state. Weight management strategies can have negative connotations for jockeys and there is now increasing evidence to suggest that the methods employed by jockeys are having negative effects on physical health (Leydon & Wall, 2002; Warrington et al., 2009), mental health (Losty et al., 2019) and riding performance (Wilson et al., 2014b). The jockey population have been previously reported to have low energy availability when compared to relative criterion values for age and demographics (Loucks, Kiens, & Wright, 2011; Wilson et al., 2014a). While jockeys are reported to utilise archaic methods to manage body mass, which have deleterious effects (Martin et al., 2017), it is unknown if jockeys adopt license-specific weight management strategies or if approaches are common to all jockeys.

2.3.3 Body composition and performance implications

Body composition and maintaining a low body fat percentage plays an important role for a jockey with a continuous requirement to align their body mass with stipulated racing weights (Wilson et al., 2020). There are also athletic considerations wherein body composition profoundly affects performance in weight category sports (Ackland et al., 2012). Dual energy X-ray absorptiometry (DXA) has been frequently used to report body fat percentages with jockey populations (Dunne et al., 2020; Warrington et al., 2009; Wilson et al., 2015) while jockey specific equations have recently been formulated to estimate body fat percentage from 8 skin fold sites (Dunne et el., 2020). It is suggested both the jockey specific equations and DXA can be used interchangeably with a high level of precision between methods (Dunne et al., 2020) however both methods present measurement error with monitoring lean athletes (Ackland et al., 2012). For practitioners and athletes in weight category sports, it is suggested that to reduce measurement error, standardised and discipline specific equations are formulated to measure body fat percentages due to unique body types (Dunne et al., 2020). Despite the need for jockeys to ride at their lightest racing weight relatively high amounts of body fat have been reported (Warrington et al., 2009; Wilson et al., 2012; Wilson et al., 2014). Warrington et al. (2009) reported mean percentage body fat for flat (8.99%) and NH (10.42%) jockeys however recent evidence suggests that both flat (15%) and NH (15.5%) body fat percentages are increasing (Dunne et al., 2020) having direct training implications for S&C practitioners. Interim research by Dolan et al. (2012) confirms the rising trends. While poor dietary habits are reported to contribute to body fat percentages (Wilson et al., 2012), there is a paucity of research around jockeys training habits which may assist athletic development interventions and effective body composition maintenance.

Jockeys frequently employ weight loss strategies in Irish horse racing to make riding weight on race day with a mean loss of 3.6 ± 2.4% of body mass with a higher limit of 10.5% (Dolan, Cullen, McGoldrick, & Warrington, 2013). A loss of 4% body mass causes jockeys to present in a dehydrated state when urine specific gravity (USG) is measured

(Dolan et al., 2013). Dolan et al (2013), also identified that a loss of 4% body mass over 48-hour period reduced aerobic capacity using an incremental treadmill test while there was no change to cognitive function recorded. It is difficult to draw accurate conclusions from the results as weight loss strategies were not controlled and therefore jockeys utilised a variety of means including active and passive dehydration to achieve the desired weights. In a simulated racing environment however, a 2% loss in body mass after a period of rapid weight loss of 40 minutes in a sweat suit reduced pushing frequency on a horse racing simulator (Wilson et al., 2014). While the physical performance metrics differ in both studies, the findings may prompt that the time frame of weight loss may be an important factor for retention of performance with a chronic method of body mass reduction favourable. Moreover, there is research to indicate safe methods of intentional body mass loss and body mass maintenance for apprentice jockeys (Wilson et al., 2015). Intermittent fasted exercise in addition to increased protein in the diet can improve jockeys strength capacities (Wilson et al., 2015). Furthermore, maintenance of increased dietary protein in addition to aerobic exercise will also reduce body fat over time (Wilson et al., 2015).

2.3.4 Jockey lifestyle

Jockeys lead a physically (Wilson et al., 2013) and psychologically (Losty et al., 2019) challenging lifestyle. A high prevalence of depressive symptoms and perceived stress have been reported among amateur and professional jockeys (Losty et al., 2019), with no significant difference reported between flat and NH jockeys. Injury, societal pressure and high levels of perceived stress contributed towards symptom prevalence. These findings are comparable to elite athletes in a multitude of sports from the United Kingdom and Holland (King et al., 2020). While jockeys compete in race meetings throughout the year (Wilson et al., 2015), unlike many other professional athletes, jockeys also work a large number of hours outside of racing (Greene et al., 2013). Australian apprentice jockeys work for a total of 24.6 ± 6.9 hours per week in addition to racing (Greene et al., 2013). A typical working day for a jockey can include 'riding out', sport specific 'work' (fast paced riding) and 'schooling' (specific practice for races often involving jumping). Additional hours include walking, 'mucking out', brushing horses and carrying buckets of feed and water to the horses (Wilson et al., 2013) however the duration of these activities or total working hours was not detailed and warrants investigation. Many jockeys also do freelance work often travelling long distances between trainer's yards and racecourses on a day to day basis to ride out and work. While work commitments have been reported for Australian apprentice jockeys (Greene et al., 2013), similar information is not available for the professional Irish cohort. An understanding of work and racing commitments of Irish jockeys would allow performance teams inclusive of nutritionists, sports psychologists and S&C coaches to implement evidence based practices focused on the constraints and daily requirements of working as a professional jockey in Ireland.

Excluding nutritional practices, there is a paucity of research on a jockey's lifestyle practices and physical activity outside of racing and working. Previous research has reported exercise such as walking, running and swimming was prominent with South African jockeys (Labadarios et al, 1993) however, exercise habits do not appear prevalent for all jockeys. Jockeys in New Zealand reported a belief that additional exercise to riding may increase muscle mass and lead to a gain in body mass (Leydon & Wall, 2002). Despite evidence existing on the benefits of an exercise programme for jockeys weight management (Wilson et al., 2014), exercise habits amongst Irish or British jockeys have not been reported. Furthermore, the perceptions surrounding exercise and physical preparation strategies remain unknown for jockeys in Ireland.

While the research shows some positive lifestyle habits occur, cultural barriers inhibit the wholescale development of optimal high performance practices (Martin et al., 2017). In this context, it is currently unknown if jockeys train to meet the demands of racing or partake in any physical activity outside of equine duties. Cultural attitudes and perceptions within the industry must be challenged while the athletic ability of a jockey and link to performance should be investigated and promoted (Martin et al., 2017). Additionally, there is a current dearth of information relating to hours spent working, riding and racing by jockeys, which would enable S&C practitioners to estimate and prescribe appropriate training load with consideration to their riding commitments.

2.3.5 Jockey injuries and falls

Horse racing is classified as a dangerous and high-risk sport (Forero Rueda, Halley, & Gilchrist, 2010; Hitchens, Blizzard, Jones, Day, & Fell, 2009). Traveling at velocities of up to 65km/hr, while manoeuvring a thoroughbred animal weighing up to 500kg around a course with obstacles (NH racing only), horse racing has a high occurrence of falls (O'Connor et al., 2017; Forero Rueda et al., 2010; Hitchens et al., 2010). These falls are both frequent and unpredictable with jockeys typically experiencing one fall every 20 rides in NH racing and one fall every 250 rides in flat racing (O'Connor et al., 2017). Resulting injuries, which include fractures and concussions, are inevitable (Balendra et al., 2008) and may lead to depressive symptoms with particular reference to long layoffs (Losty et al., 2019). Falls while 'riding out' are not as frequent, however they tend to cause serious injury and can negatively affect jockeys financially with an inability to ride a race (O' Connor et al., 2020). While many injuries require short rehabilitation time frames such as commonly occurring fractures, some injuries are catastrophic which can end racing careers or in extreme circumstances can cause death (Balendra et al., 2008). With low levels of aerobic fitness associated with a higher risk of injury from falls in horse racing (Hitchens et al., 2011a), there is a need for an investigation into injury prevention strategies (O'Connor et al., 2017) but also physical preparation strategies. Jockey bone health is and has been the focus of much research which has reported poor markers of bone health for this athlete population (Dolan et al., 2011, 2012a; Waldron-Lynch et al., 2010; Warrington et al., 2009). Jockeys with lower bone mineral density are at greater risk of injury from impacts as a result of falls (Greene et al., 2013). Osteopenia is also prevalent among some jockey populations (Leydon & Wall, 2002). S&C can form an important intervention designed to increase the load bearing capabilities of bone and reduce the risk of injury from falls (Greene et al., 2013). S&C interventions may benefit jockey's bone health. It is understood that increased bone mass and strength during growth is the primary strategy for the prevention of osteoporosis in later life (Cumming et al., 1997). While the literature unequivocally supports the implementation of S&C and vigorous physical activity, which provide a sufficient osteogenic stimulus to improve bone health (Kohrt, Bloomfield, Little, Nelson, & Yingling, 2004; Layne & Nelson, 1999), it is currently unclear if jockeys partake in S&C activities or indeed any external training to riding which may increase bone health markers and the risk of injury from falls.

2.4 Physiological demands of equine sports

2.4.1 Physiological demands of horse racing

There has been limited published data on the physiological demands which race racing imposes on a jockey. Athletes in other codes are commonly assessed using a variety of physiological and performance monitoring methods to estimate appropriate training load, screen for overtraining and to empower coaches to match training with the physiological demands of the sport (Kraemer et al., 2009; Li et al., 2016; Taha & Thomas, 2003). It has been suggested that both aerobic and anaerobic energy systems are active during racing (Cullen et al., 2015; Trowbridge et al., 1995), however it remains an area which requires further study.

Skeletal muscle can exert force with oxygen using the aerobic system or without oxygen using the anaerobic system (Cardinale et al., 2011). For very short periods, muscles can contract using molecules within the muscle such as ATP, creatine phosphate, glycogen and glucose combined with a few breaths of oxygen consumption (Brooks, 2020). For activity of prolonged duration, such as professional horse racing, glycolsis and cell respiration may be required to provide energy to sustain activity (Brooks, 2020; Stanfield & Germann, 2011). The use of fuels is dependent on intensity and duration of activity (Brooks, 2020). If a jockey begins riding at a low and gradual intensity, a greater proportion of ATP is generated from aerobic metabolism (Stanfield & Germann, 2011). Exhaustive high intensity exercise lasting several minutes requires energy from both the aerobic and anaerobic energy systems (Cardinale et al., 2011). Anaerobic metabolism is deemed important for repeated short and high intensity efforts under approximately 300 seconds (Cardinale et al., 2011) which is common in racing.

Aerobic capacity can be measured using incremental tests to volitional exhaustion (Foster et al., 2015) while anaerobic capacity is generally measured using invasive measures such as blood lactate measurement or non-invasive methods such as exercise tests of critical power (Cardinale 2011). Research obtained from maximal aerobic tests shows jockeys to be physically fit individuals (57.54 ± 4.71 $ml \cdot kg^{-1} \cdot min^{-1}$) comparable to other professional athletes in sports such as soccer (O'Reilly et al., 2017). Previously trainee and apprentice Irish jockeys have exhibited peak oxygen uptake ($\dot{V}O_{2peak}$) values of 57.1 ± 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$ and 54.0 ± 3.3 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively (Cullen et al., 2015) while to the best of the author's knowledge, no normative data for field tests or anaerobic tests exists in the literature. Whilst appreciating that jockeys must maintain a sufficient level of physical conditioning to compete in several races each day, up to 7 days a week with no defined seasons (Dolan et al., 2011; Warrington et al., 2009), the following section will discuss the known demands on fitness in respect to flat and NH horse racing.

While horse racing is suggested to be a physiologically demanding sport (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge, 1995), there is limited information in relation to the specific physiological demands of both flat and NH racing, particularly comparing race distances between and within the different racing licenses. In horse racing, the jockey is perched 3m above the ground in a position of forward propulsion and executes dynamic movements requiring great muscular strength, endurance and balance in order to coordinate a dual partnership with the horse (Turner, McCrory, & Halley, 2002). Jockeys must ensure they control their own performance while also regulating the performance of the horse (Kang, Chaloupka, Mastrangelo, Biren, & Robertson, 2001; Speed, 2007). O'Reilly, Cheng & Poon (2017) detailed max HR values of 186 ± 14 $b \cdot min^{-1}$ using a polar HR monitor in competition with 20 professional flat jockeys. The race data closely mirrored mean maximal values attained from the same jockeys while completing a maximal treadmill test (185 ± 8 b·min^{-1}). Although the focus of this study was to measure HR in hot and moderate climatic conditions over two race days, there was no reference to racing distance or duration which may affect HR response. While there are obvious limitations when comparing amateur and apprentice jockeys due to a difference in riding experience, similar peak heart rates among 8 Irish apprentice jockeys in flat races have been reported (189 ± 5 b·min^{-1}). HR was reported from the Equivital physiological monitoring system (EQ02; Hidalgo, Cambridge, United Kingdom) (Cullen et al., 2015). Race distance ranged from 1200-1600m. In a simulated 1400m race with 18 trainee jockeys, a lower peak HR was reported (161 ± 16 b·min^{-1}). While the trainee jockeys reported a higher aerobic capacity during maximal tests, a lower HR may be explained by a simulated environment underestimating the physiological demands of riding (Ille et al., 2015). A maximal incremental cycle ergometer test allowed the interpretation of relative maximal values for both the competitive and simulated race. Higher relative HR_{peak} values were reported in the real environment (103 ± 4 %HR_{peak}) versus the simulated environment (86 ± 7 %HR_{peak}). Similarly, the real race also recorded higher relative mean HR values (98 ± 4 % HR_{peak}) contrasted with the simulated race (77 ± 7 % HR_{peak}). A portable gas analyser was also used in the simulated trial reporting a $\dot{V}O_{2\ peak}$ of 42.7 ± 5.6 ml·kg^{-1}·min^{-1} (75 ± 11 % $\dot{V}O_{2peak}$). While the use of a portable gas analysis system for measuring $\dot{V}O_2$ would not be permitted during race riding, it is possible the physical characteristics required in a simulated environment may underestimate that of a real race. While physiological comparisons are drawn in the study, two different jockey cohorts were analysed which presented with significantly different fitness levels ($p \leq 0.05$). Future comparative studies should look at using the same population over repeated trials. In summary, further monitoring of jockeys in competitive flat racing is required, particularly in the area of anaerobic responses through lactate analysis which has not been investigated previously (Cullen et al., 2015).

Only one study currently exists monitoring jockeys in competitive NH racing (Trowbridge et al., 1995). Seven male jockeys were measured over a variety of race distances that lasted between 4 minutes and 6 minutes 50 seconds. The race distances were not specified. Peak HR values of 162-198 b·min^{-1} were reported during racing using a PE3000 Sport Tester monitor sampling every 5 seconds. While novel research, an update in the literature is required with a greater focus on the physiological demands relative to race distance. Peak post-race lactate levels ranging from 3.5 to 15 mmol·l^{-1} were also reported within 15 minutes post-race (Trowbridge et al., 1995). Although a small sample of jockeys (n=7) were monitored, it was concluded that jockeys performed close to their maximum capacity during racing. While Wilson et al. (2013) reported the estimated energy demands (43kcal) of nine NH jockeys on a simulator over an estimated 3.2km race, however evaluating the physiological demands was not the aim of the study. While neither HR or lactate responses were reported there was no significant difference between the Polar RS400 heart rate monitor (Kempele, Finland) and the Actiheart monitor (Cambridge, UK) for the calculation of energy expenditure (EE) during 30 minutes of exercise when compared with respiratory gas analysis (n=9). HR monitors may therefore be used within an equine environment for the monitoring of HR and aiding the calculation of EE during physical activity.

Wide ranges in physiological values may be explained by the variability in individual responses from both jockey and horse (Devienne & Guezennec, 2000) however the variance reported in lactate responses prevents practitioners from understanding which energy systems are predominantly in play. There is a current paucity of research in NH racing and a more in-depth investigation on the physiological demands placed on jockeys is warranted. Physiological demands with respect to race distance and time may provide data on the relative demands placed on jockeys. While it is understood that horses travel at higher velocities in flat racing in comparison to NH racing we are unsure what physiological effects, if any, this has for the jockey during competition. Furthermore, it is not known if longer or shorter races expose the jockey to greater physiological demands in either flat or NH racing. Relative demands would aid practitioners in specific training plans to improve the capacity of the relevant energy systems. It is hypothesised that shorter races may exhibit higher intensity responses than longer races where the horse travels at a lower velocity.

2.4.2 The physiological demands of non-racing equestrian activity

With a lack of information on the physiological demands of horse racing, other forms of equestrian sport may provide a reference point for jockeys. Recreational riding, dressage, show jumping and cross country have all been explored in relation to the demands in addition to specific analysis of the demands in relation to specific riding gaits (Devienne & Guezennec, 2000; Kang et al., 2001; Kiely et al., 2019a; Roberts, M., Shearman, J., & Marlin, 2009). Common to all events, there is a sequential rise in oxygen consumption between walk, trot and canter (Devienne & Guezennec, 2000; Kiely et al., 2019a). Relative mean $\dot{V}O_2$ corresponded to 15 ± 4%, 38 ± 6%, 47 ± 9% of $\dot{V}O2_{peak}$ for Irish trainee jockeys for each riding gait respectively while mean HR corresponded to 48 ± 6%, 60 ± 6%, 71 ± 7% of HR_{peak} respectively. While governing authorities prevent the monitoring of oxygen consumption in competition, it is plausible that a rise in blood lactate concentration may also occur from walk to canter as is also seen with mean HR (Kiely et al., 2019a). During events that require faster riding gaits and jumping such as cross-country, the rider adopts an un-seated position, similar to that of a jockey with weight bearing through the legs of the rider in an isometric semi-squat position (Roberts et al. 2010). Variances in body position in the equestrian modes are likely to require changed movement patterns which require the activation and recruitment of position specific and different muscle groups (Douglas, 2017). In the cross country phase of eventing, high mean blood lactate concentrations (9.5 ± 2.7 $mmol{\cdot}L^{-1}$) and HR (184 ± 11 $b{\cdot}min^{-1}$) were reported as riders manoeuvre and jump obstacles (Roberts, Shearman & Marlin, 2009); the reported values similar to those previously described in horse racing (Cullen et al., 2015; Trowbridge et al., 1995). While isometric bouts and maintenance of balance have been attributed to an increase in blood lactate concentration (Sainas et al., 2016), the literature proposes increasing reliance on the anaerobic pathways as distance and frequency of jumps increase. It is evident that eventing displays high physiological demands, however ‘riding out’ does not impose high physiological stress or intensity on the rider when comparing mean HR while cantering on the flat (135 ± 15 $b{\cdot}min^{-1}$) to the limited body of evidence currently available in professional flat (167 ± 12 $b{\cdot}min^{-1}$) (O'Reilly e al., 2017) and NH (136 to 188 $b{\cdot}min^{-1}$) (Trowbridge et al., 1995) racing. While the physiological requirements and energy demands have been researched in equestrian sports, direct comparisons with horse racing may not be accurate with horses moving at a higher velocity in racing and variations in body positions reported.

While a gap in the literature has been identified in horse racing, the physiological demands required to control thoroughbred horses in showing jumping, dressage and cross country have been extensively investigated (Devienne & Guezennec, 2000; Douglas, 2017; Roberts, Shearman & Marlin, 2009). While there are nuances in riding position and the rules of the aforementioned equestrian sports, the presented research provides information on what a jockey may experience during riding gaits of walk, trot and canter which are routinely experienced during 'riding out' for jockeys (Kiely et al., 2019a).

2.5 Environmental influences on human physiology during racing

Internal and external influencing factors including the competitive environment, physiological requirement of the sport and biological status of the athlete are associated with performance outcomes in both team (Hoffman, 2008), individual sport (Abbiss et al., 2010) and equine sport (Hitchens, Blizzard, Jones, Day, & Fell, 2011). In the following section, internal and external factors which may affect the performance of the jockeys will be investigated. External influencing factors will relate to variables that are outside the control of the jockey. Internal influencing factors will explore variables which are directly related to a jockey's actions. Where research has not been conducted in an area relating to jockeys, other equine and individual sports will be explored.

2.5.1 External influencing factors on physiological responses

2.5.1.1 Riding gaits

Only one previous study (Kiely et al., 2019a) has investigated if a horse's increasing velocity increases the demands placed on the jockeys. While 'riding out' imposes only light to moderate stress on the aerobic and anaerobic energy systems (Devienne & Guezennec, 2000; Kiely et al., 2019a), it is understood that as a horse increases velocity, the physiological demands for the rider increase. This is evident in riding out (Kiely et al., 2019a), dressage (Devienne & Guezennec, 2000) and eventing (Douglas, 2017). Reports of mean HR during the riding gaits of walk (91 ± 9 b·min^{-1}), trot (115 ± 11 b·min^{-1}) and canter (135 ± 15 b·min^{-1}) expose jockeys to lower hearts rates in comparison to the limited research available in racing (Kiely et al., 2019a). Additionally, walking and trotting in English eventing riders only marginally involved anaerobic glycolysis, while cantering induced a moderate but increased CO_2 excess production when compared to a maximal, incremental exercise test on a cycle ergometer (Sainas et al., 2016). It can be concluded that only cantering was able to considerably activate the glycolytic system (Sainas et al., 2016). Future research is required to investigate the demands of galloping which was not investigated by Kiely et al. (2019a) due to safety concerns using a portable gas analysis system at high velocities.

Changes to the kinematics between horse and rider in addition to biomechanical adaptions of the rider to the increasing velocity can result in higher levels of muscular activity with particular reference to the trunk musculature. This increased activity is reported to be for both stabilisation and co-coordination between horse and jockey (Sainas et al., 2016). While an increase in velocity has been noted to increase the metabolic cost of physical activity in riding gaits progressing from walk to canter (Kiely et al., 2019a), velocity itself may not be a useful indicator of exercise intensity for sports where surface, terrain or ambient temperature frequently change (Jeukendrup & Van Diemen, 1998). This is relevant for practitioners to consider in sports such as cycling and also horse racing where the athlete has little control over the terrain.

2.5.1.2 Ground conditions & animal temperament

Ground conditions known in horse racing as ‘going’ can fluctuate greatly from ‘heavy to firm’. Heavy conditions describe a ground state when the soil is saturated with water from rainfall (Sheridan & Sweeney, 2001). Major flat races take part in the summer with firm ground preferred while NH races which take place over obstacles with softer ground conditions preferred. In the softer ground, the hoof of the horse could sink 10-15cm into the soil. The resulting leg action can differ dependent on the ground and the horse’s natural gait having implications for the economy of the jockey (Sheridan & Sweeney, 2001). Jockeys may need to restrain or encourage the horse in various ground conditions or tactical scenarios while racing in which they can increase or decrease their own physical effort. However, it is also reported true that a ”keen” or “lazy” horse can directly increase a rider’s exertion (Devienne & Guezennec, 2000).

2.5.1.3 Climatic Influences

Seasons and climatic conditions can vary for jockeys. Pioneering research investigating HR responses and hydration status via USG in moderate (MOD) (17ºC and 60% humidity) and hot climatic (27ºC and 90% humidity) conditions was undertaken with Hong Kong Jockey Club. No significant difference was noted between race day HR recordings in both conditions with jockeys operating at approximately 90% of HR_{peak} during each race (O’Reilly et al., 2017). There was also no effect of moderate and hot temperatures on hydration status (USG HOT: 1.025 ± 0.006; MOD: 1.026 ± 0.026 (O’Reilly et al., 2017). The methodological approach adopted in this study does not however report the duration of the races on both testing occasions and whether the same distance race was utilised on both testing occasions. Consequently, the effect of exercise duration on mean HR in the different conditions is not considered.

With only one known study on the effect of temperature on performance has been completed in an equine domain, other individual sports may provide useful insights. While jockeys are not seated, cyclists perform eccentric and concentric actions while in a forward leaning position with flexion at the knee and hip similar to jockeys. An increase in temperature from 15°C, 25°C to 35°C was found to cause a gradual reduction in both muscle activation and power output when the same perceived effort was observed (Tucker, Rauch, Harley, & Noakes, 2004) when contrasted to cold conditions at 10°C (Abbiss et al., 2010). A temperature at 10°C in moderate humidity of 65% was found to have no negative effect on muscular recruitment or power output when compared to a control group (Tucker et al., 2004). Furthermore, the rating of perceived exertion (RPE) measured using the 15-point (6–20) Borg scale (Borg, 1982) is not thought to be influenced by hypothermic induced strain at 10°C (Abbiss et al., 2010). Fatigue responses during high temperatures (30-35°C) are thought to be caused by a reduction in the function of the central nervous system due to an increase in core temperature to 40°C (González-Alonso et al., 1999; Tucker et al., 2004). Exercise in the heat also causes central fatigue in sports which is associated with reduced muscular recruitment with prolonged isometric contractions (Tucker et al., 2004). While this study was completed in cycling time trials with longer durations than exercise bouts in racing, it is feasible that a similar effect can be found in jockey athletes who sustain a prolonged isometric contraction. While once thought to play an active role, recent research has indicated that cardiac output, substrate availability or an increase of lactate are not primary contributors to performance reduction while performing exercise bouts in heat with a reduction in skeletal muscle recruitment instead cited (Tatterson, Hahn, Martin, Febbraio, & Movement, 2000; Tucker et al., 2004). Temperatures which encourage optimal physiological function have been reported at 10°C and 11°C while higher temperatures of 15°C are advantageous for explosive contractions (Nimmo, 2004; Tucker et al., 2004). Other contributing factors to heat stress in jockeys may include the heat radiated from the horse or indeed the jockey's protective clothing. To the best of the author's knowledge, no research investigating thermoregulatory factors during race riding has been completed. In summation, in the absence of these metabolic changes, sufficient heat to cause a rise in core temperature can have a negative influence on the central nervous system impacting cerebral blood flow, optimal brain activity and cause reduced muscle activation (Cardinale et al., 2011).

2.5.1.4 Influences of riding equipment

Safety regulations imposed by International governing authorities of horse racing mandate that jockeys are required to wear protective clothing which includes a helmet and protective vest in addition to racing colours (silks), breeches (trousers) and boots (Wilson et al., 2014). Personal protective equipment which is counted against the jockeys weight allowance can moderate heat or cold temperatures and act as a protective mechanism against thermal stress (Gavin, 2003). In other sporting codes, it is understood protective clothing can affect the dissipation of heat from the skin with clothing which facilitates the least resistance to evaporation preferred (Gavin, 2003). In warm temperatures, this can elevate temperature and HR (Armstrong et al., 2010; Gavin, 2003). Little research has investigated relationships between clothing and performance or clothing and thermoregulation in racing but research on equestrian helmets have proposed that cooling performance of riding helmets can be improved with design features based on cycling helmets with air inlets and outlets specifically featured (Bauwens, De Graaf, Vermeir, Mukunthan, & De Bruyne, 2019). With concussions prevalent in racing (O'Connor et al., 2017; Piantella, McDonald, Maruff, & Wright, 2020) safety features will however dominate the design. In addition to protective equipment, sweat is the main form of heat transfer with the environment for a horse. While not researched, it is plausible that a heat transfer can exist between horse and rider (Douglas, 2017) having physiological implications for the jockey. Additional factors such as a horse's riding equipment known as 'tack' can also influence the performance of both rider and horse (Peham et al., 2004). An inappropriately fitted saddle can disturb the communication between horse and rider. The resulting unstable saddle can unbalance the rider and the ability of the horse to move forward with a consistent running gait. When the motion of the rider becomes too variable, the horse's natural rhythmic movements can be disturbed increasing the risk of falling or collision with obstructions (Peham et al., 2004).

In summary, while a rider must focus on controlling the horse while applying tactical maneuvers, external factors are at play which can directly influence the physiological function and performance of the athlete. Horse riding equipment and ground conditions may have direct implications for a jockey's physiological status and efforts should be made by practitioners to replicate competition conditions to minimise any interruption to both the jockeys and horses riding gait during competition.

2.5.2 Internal influencing factors on physiological responses

2.5.2.1 Within subject biological status

Within subject variation and variability must be deliberated in the collection and the interpretation of findings. Variability in physiology and biological status can vary day to day in athletes (Achten & Jeukendrup, 2003). The body tries to maintain constant conditions in the internal environment, also known as homeostasis, which is a central organising principle of physiology (Stanfield & Germann, 2011). Homeostasis in athletes is threatened by physiological and psychological events often referred to as "stressors" (De Kloet, Joel & Holsboer, 2005). If the stressor is recognised by the brain as stable alertness, focused attention and cognitive processing can be potentiated. However, if stressors are recognised by the brain as unstable they generate physiological responses with activation of the sympathetic nervous system and a release of adrenaline and noradrenaline. These can have direct physiological implications for jockeys such as decreasing clearance of blood lactate from the working muscles (Hamann, Kelley, & Gladden, 2001) while also increasing HR (adrenaline) and initiating vasorestriction of the blood vessels (noradrenaline) which in turn increases blood pressure (Stanfield & Germann, 2011).

Time dependent changes known as circadian rhythms can affect performance parameters including strength, muscular power and HR response to exercise (Atkinson & Reilly, 1996). While the differences in an individual's rhythms are usually minor, they can be significant (Atkinson & Reilly, 1996). Circadian rhythms and diurnal variation have not been previously researched in a jockey population to the best of the author's knowledge. While it has been acknowledged in most research that certain biological rhythms are present and varied (Dalton, McNaughton, & Davoren, 1997; Teo, Newton,

& McGuigan, 2011),Dalton, McNaughton, & Davoren (1997) found no effect of circadian rhythm on performance in cycling time trials of 15 minutes' duration. The main body of literature from sports outside of horse racing contradict this and would suggest that both aerobic and anaerobic power in addition to strength improves throughout the day (Teo et al., 2011). As jockeys ride out in the morning, no racing occurs at this time so circadian rhythm may not have a negative effect during race times in Ireland. Special attention may need to be given to jockeys who compete internationally and travel across time zones.

2.5.2.2 Internal biological responses to training

Changes which result in increased function within specific physiological systems are regulated by local metabolites, neural signals and hormonal signals (Stanfield & Germann, 2011). Both respiratory and cardiac function increase immediately at the onset of exercise (Stanfield & Germann, 2011). The cardiovascular system plays an important role in maintaining homeostasis both at a cellular and global level during exercise. While maximum heart rate is fixed, stroke volume is trainable with increases observed both at maximal and submaximal intensities (Saltin, 1968). An increase in stroke volume can contribute to an increase in $V0_{2max}$ (Saltin, 1968). However, a recent re analysis of the methods used by Saltin (1968) found that the enhanced $V0_{2max}$ was a result of enhanced diffusional conductance of O_2 between mitochondria and the red blood cells, rather than increased blood flow as the major contributor (Wagner 2015). Although the mechanism is debated, it can be concluded that $V0_{2max}$ will improve with a relevant training stimulus to create a state of cardiovascular overload (Cardinale et al., 2011). Adaptation to this overload can facilitate a jockey to increase cardiac output from the left ventricle which increases blood volume, myocardial contractility and the potential to carry oxygen through red blood cells to the working muscles (Cardinale et al., 2011). The lungs provide a vital link between the atmosphere and the cardiovascular system with its function closely reliant on the diffusion capacity of the pulmonary system (Dempsey et al., 2006a). Aerobic training can result in a more efficient ventilatory system while increasing mitochondrial density (Cardinale et al., 2011) but has little or no effect on the structure and function of the lungs (Dempsey et al., 2006b).

As a result of aerobic glycolysis, lactate production is a continuous process during rest and exercise and is used as an energy source, a signaling molecule and the major gluconeogenic precursor (Brooks, 2020). During exercise which requires short term high-intensity efforts the production of lactate in the muscles is increased while lactate clearance is slowed. The associated increase in blood lactate accumulation is related to a multitude of interrelated physiological and biochemical reactions rather than oxygen limited oxidative phosphorylation. This results in increased intramuscular lactate concentration and also an increased net output of lactate into the blood (Gladden, 2004). During recovery, the resting or less stressed muscles uptake lactate from the blood and oxidative muscle fibres can oxidate the substrate.

As homeostatic perturbations are likely to affect fatigue resistance, interventions which ameliorate biological limiting factors should improve repeated high intensity efforts (Cardinale et al., 2011). Practitioners can focus on recreating the competition environment exposing the athletes to relevant stressors to facilitate adaptation and in turn constructing efficient biological coping mechanisms (De Kloet, Joel & Holsboer, 2005).

2.5.2.3 Riding position considerations

Riding position has received little attention in the horse racing research. It is unknown how changes to riding position can affect both muscular and/or biological demands. While riding position may be considered an external variable, the focus of this section will be the aspects of riding which is within the rider’s control and not those which are not reactions to that of the horse. During unseated cantering and jumping in horse racing a greater muscular drive is reported (Trowbridge et al., 1995). Jockeys can also adjust their stirrup leather length to their preferred riding style (Wilson et al., 2013). While it is common that flat jockeys ride with a short stirrup and NH jockeys ride with a longer stirrup, jockeys have individual preferred riding lengths. The weight through both left and right stirrup is asymmetrical and can be significantly different while a horse gallops. This may be caused by a jockey's centre of mass displacing laterally away from the horse's lead leg (Walker et al., 2016a). A jockey's ability to hold a stable pelvis and minimise movement while riding is thought to enhance the dual performance of horse and jockey (Walker et al., 2016a). The ability of a jockey to hold a stable position with particular focus to musculature around the pelvic girdle should thus be a focus for physical preparation professionals. While obtaining position relevant stress it provides an opportunity for jockeys to be exposed to specific physiological stress.

Electromyography (EMG) research in the trot riding gait identified the importance of muscular endurance as a physical attribute due to long periods spent with muscles in tonic contraction to maintain posture (Terada et al. 2004). Conversely, a jockey's posture is not that of a seated position. Jockeys utilise their lower limbs to isolate their centre of mass in an unseated position while minimizing movement and attaining a position as close to the midline of the horse as possible (Walker et al., 2016b). While high peak heart rates are presented in the research during racing (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995), Spurway (2007) proposes that in sports such as sailing where athletes sustain prolonged isometric contractions that a "quasi-isometric" effect may elevate the HR above the oxygen cost which that exercise demands. This occurs at approximately 40% of maximal voluntary contraction (Vangelakoudi, Vogiatzis, & Geladas, 2007). Research typically suggests HR and $\dot{V}O_2$ have a well-founded linear relationship in submaximal exercise (Achten & Jeukendrup, 2003) however there are cases where we see a change in this dynamic. The quasi-isometric effect experienced by sailors can equate to roughly 50% of the total metabolic demand (Spurway, 2007). A quasi-isometric effect can minimise blood flow and reduce 'hiking' performance in sailing as static stresses are imposed on the quadriceps and abdominals (Vogiatzis, 1996). While the blood flow is restricted, it is not fully occluded (Spurway, 2007) and a resulting rise in HR occurs. While it is proposed that fitness training for sailors should involve sustained quadriceps stress, research has found no statistically significant association between hiking endurance and isometric strength of the quadriceps with sailors (Vangelakoudi et al., 2007). Furthermore, there was no significant difference between sailors who sustain frequent isometric stressors and aerobic endurance athletes when performing hiking activities. In relation to blood biomarkers no significant association between EMG and blood lactate concentration levels were discovered (Vangelakoudi et al., 2007) indicating that maybe only HR is directly affected by a quasi-isometric effect.

It is not known if jockeys are affected by a quasi-isometric effect in flat or NH racing. It is speculated that isometric muscle activity may affect a jockey's physiology with a decrease in blood flow and elevated HR response while riding. However, it is not known what level of stress the isometric position entails for a jockey or indeed if a required percentage of their maximal voluntary contraction is met for the quasi-isometric effect to occur when riding. While trying to quantify the effect of the isometric contraction in racing is outside of the scope of this thesis, future research may investigate the percentage of maximal voluntary contraction jockeys are exposed to while racing.

2.5.2.4 Effect of making weight

Though not unique to horse racing, low energy availability has repercussions for both male and female athletes relative to performance (Leydon & Wall, 2002; McGuire, Warrington, & Doyle, 2020). Recently coined as RED-S (relative energy deficiency in sport) (Statuta, Asif, & Drezner, 2017), low energy availability and in turn depleted glycogen levels cause a reduction in the ability to produce high blood lactate concentration levels (Moquin & Mazzeo, 2000). With respect to health, there are further implications for female jockeys. While female jockeys are potentially lighter with less lean mass than their male counterparts, chronic low energy availability remains prevalent (Leydon & Wall, 2002). Implications for females include a potential negative association between energy availability, energy demand and the female athlete triad (Wilson et al., 2014a). While the athlete triad is a condition that has focused mainly on female athletes, a systematic review of the literature suggests males, particularly in weight category sports, may present with related symptoms (McGuire et al., 2020). Intentional dehydration strategies are also frequently employed to reduce body mass before racing (Wilson et al., 2014a). Dehydration and associated heat stress have previously been accentuated to cardiovascular drift and a resulting increase in HR (Achten & Jeukendrup, 2003; Labadarios et al., 1993). This can have a profound effect on the HR-$\dot{V}O_2$ relationship (Achten & Jeukendrup, 2003). Supplementary evidence also exists of a strong relationship between dehydration and increased levels of adrenaline and noradrenaline concentration (Moquin & Mazzeo, 2000).

Initial research on thermal dehydration which is frequently employed by jockeys (Dolan et al., 2011) details that a 5% body mass loss can alter the onset of blood lactate accumulation (Jacobs, 1980) while evidence also exists of a shift in blood lactate threshold with a 1.5% loss of body mass (Moquin & Mazzeo, 2000). High correlations between lactate and adrenaline concentrations in athletes indicate that a shift in lactate threshold may partly be attributed to an increase in epinephrine (Moquin & Mazzeo, 2000). This follows pioneering research which indicted that reduced blood lactate concentrations are evident in both maximal and submaximal exercise when athletes presented in a dehydrated state (Saltin, 1964). While some researchers in both field and endurance sports indicate that mild levels of dehydration (<2% loss of body mass) can reduce cognitive function, increase HR (Armstrong et al., 2012) accelerate fatigue (González-Alonso, Calbet, & Nielsen, 1999a) and reduce aerobic function (Cheuvront et al., 2010), this is not evident in all sporting populations (Edwards & Noakes, 2009). It is proposed this is due to disturbances to both metabolic and thermoregulatory pathways caused by carbohydrate degradation and increased vascular resistance decreasing skin blood flow (Cheuvront et al., 2010; Gonzàlez-Alonso et al., 1999) and also due to reduced heat dissipation due to lower blood volume, stroke volume and sweat production (Armstrong et al., 2007).

It is proposed that dehydration is an element of a larger complex regulatory system and a 2% loss in body mass as a specific threshold for performance decrements is not accurate (Edwards & Noakes, 2009). The mode of weight loss and proximity to racing may be important for practitioners to consider. Sport scientists and performance practitioners must consider the role of both energy deficiency and dehydration on physiological outcomes. Associations between dehydration and performance outcomes, both physiological and cognitive, are varied and this area requires further research given the regularity of acute weight loss methods in horse racing (Dolan et al., 2011). Specifically, agreed tests to assess cognitive and physiological function demands attention. Additionally, there is a lack of data surrounding HR, blood markers and dehydration in a competitive environment.

2.6 Physical fitness testing and testing battery formation

2.6.1 An Introduction to physical fitness testing

Physical fitness has been present in academia and industry for nearly two centuries however, there is no widely accepted definition of the term (Shephard, 2018). Physical fitness has been described as a combination of bodily functions that include morphological, muscular, motor, metabolic and cardiorespiratory activity (Bouchard, Shephard, & Stephens, 1994). While fitness commonly falls underneath two categories of either health related physical fitness or performance related physical fitness, the latter is the focus of this thesis section. Performance related fitness can be defined as the component of fitness for sports performance or optimal work which primarily consists of motor skills, power, speed, body composition, nutritional status and motivation (Bouchard et al., 1994).

While sports science is continually advancing, practitioners must decide between adopting new approaches with improved validity or remaining with protocols that have proven reliability for assessment of performance capabilities (Reilly, 2001) and facilitating the collection of longitudinal data sets. Performance can be measured objectively in laboratory based environments however the use of laboratory based equipment in field tests is limited due to time constraints, and the requirement of sophisticated equipment and qualified technicians. Field based testing equipment provides an alternative platform for measuring performance with low costs, ease of administration and the opportunity to assess multiple components of fitness in a short period of time (Ruiz et al., 2011; Vanhelst, Béghin, Fardy, Ulmer, & Czaplicki, 2016). Field-based testing batteries have specifically been designed for a range of professional sports including basketball (Read et al., 2014), soccer (Turner et al., 2011) and Rugby union (Dobbin, Hunwicks, Highton, & Twist, 2018); however there is a paucity of research relating to a testing battery for individual sports with a particular requirement of a physical performance testing battery in horse racing (Cullen et al., 2015).

2.6.2 Physical fitness testing in horse racing

To assess jockey fitness or determine the success of specific training interventions, a fitness testing battery is of paramount importance for the industry. A physical testing battery can facilitate the collection of normative data for an athlete cohort in addition to providing a platform to assess the success of fitness programmes (Cullen et al., 2015; Turner et al., 2011). The following section reviews the existing and limited fitness testing related research with jockeys.

While a holistic testing battery is absent in jockey research, various performance parameters have been measured but no battery is available which would facilitate data collection and collaboration in the field on an international level. Laboratory based aerobic capacity tests have been administered and show jockeys to be fit athletes while demonstrating lower values than athletes such as male cross-country skiers (83.0 ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$) who rely heavily on their aerobic capacity (Losnegard & Hallén, 2014). Similar $\dot{V}O_{2peak}$ data are reported across jockey license types as seen in Table 2.1 using incremental maximal tests on both the treadmill and cycle ergometer. It is plausible that athletes will be more economic at either running or cycling so caution should be observed when comparing aerobic capacity values when attained using different methods. Furthermore, we do not know if jockeys are frequent runners or cyclists outside of riding related work where neither mode of activity is used. Relative $\dot{V}O_{2peak}$ reported for trainee jockeys during a simulated 1400m race on a mechanical horse equated to 75% of $\dot{V}0_{2peak}$ (Cullen et al., 2015) identifying submaximal riding intensity however evidence suggests simulators underestimate the demands of race riding (Walker et al., 2016b) and therefore may not attain a true peak value. While it is logical that physiological monitoring should be completed during real race riding, safety guidelines by governing authorities in racing prohibit the use of such portable devices.

Table 2.1 Peak oxygen uptake ($\dot{V}O2peak$) values reported for jockey license types.

Jockey License Type	Mode of Test	$\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1}) Mean ± SD	Reference
Professional Flat (n=20)	Treadmill	57.5 ± 4.7	Reilly et al., 2016
Trainee (n=18)	Cycle Ergometer	57.1 ± 4.7	Cullen et al., 2015
Apprentice (n=8)	Cycle Ergometer	54.0 ± 3.3	Cullen et al., 2015

Field based tests have been used with the jockey population but no systematic protocol or normative data has been provided. Isometric strength of the lower back and legs has been measured with jockeys using a Concept 2 Dyno flywheel (Concept 2, Inc., Morrisville, VT, USA) (Wilson et al., 2014b) and a back/leg dynamometer (Gloria TTM 300 kg, Tokyo) (Hitchens et al., 2011a). Associations have also been instigated between race falls and jockey balance (unilateral standing stork pose), flexibility (sit and reach), power (CMJ) and handgrip strength (hand held dynamometer) (Hitchens et al., 2011a). However, normative data on the test results were not provided. Furthermore, jockeys neither jump nor require the need for unilateral balance while racing and therefore the validity of these chosen tests and sample sized used (n=8) may be questioned. Future research should be undertaken with a greater sample size to validate the findings of Hitchens et al. (2011a) in addition to reliability analysis of the tests.

Distinct variation in physical and physiological assessment methods inhibits the establishment of normative data (Read et al., 2014) and this is evident in horse racing. A large scale study of the physiological attributes of jockeys is required (Hitchens et al., 2011a). Establishing a reliable and valid physical fitness testing battery that can be applied nationally and internationally should be a primary objective for the governing authorities.

2.6.3 Practical Considerations for Testing battery formation

Before the formation of a testing battery, a needs analysis is advised to determine the sports biomechanical and physiological requirements (Turner et al., 2011), and therefore ensuring that sport specific parameters are examined (Currell & Jeukendrup, 2008). Research suggests that jockeys experience high physiological demands in both flat and NH racing (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995) placing stress on the alactic, lactic and aerobic energy systems (Gastin, 2001). The physical attributes required to race have been described and indicate a requirement for strength (Wilson et al., 2014b), strength endurance (Hitchens et al., 2011a), stability, flexibility, balance (Walker et al., 2016a) and aerobic power (Cullen et al., 2015).

Research in horse racing has suggested that favour be given to transportable and robust tests over tests that use extra sensitive equipment (Hitchens et al., 2011a) and that field tests should be designed so that they can be implemented in the typical training environment (Reilly, 2001). Reliable and valid testing batteries provide practitioners an opportunity to implement evidence based practice (Welk, 2017). It is important that the practitioner accounts for both test robustness and implementation of the test in the horse racing industry. Considerations for the formation and implementation of a valid and reliable physical testing battery will be outlined and critically appraised in the following sections.

2.6.3.1 Optimal order for physical testing battery formation

The primary considerations for practitioners when designing and implementing testing are validity and reliability of each test (Hopkins, 2000), however, the testing environment and sequence of tests may also influence performance outcomes for participants (Hopkins, 2000; Pescatello, Riebe, & Paul, 2014). Research has not identified an optimal testing order for multiple components of fitness (Pescatello, Riebe, & Thompson, 2014) however, the National Strength and Conditioning Association (NSCA) has proposed a testing battery structure that is outlined in figure 2.1. The proposed structure commences with non-fatiguing tests and accounts for the optimal use of energy systems and skill coordination (Miller, 2012) that maximises test reliability (Harmann, 2008). Three minutes passive rest was implemented between tests (Pescatello et al., 2014).

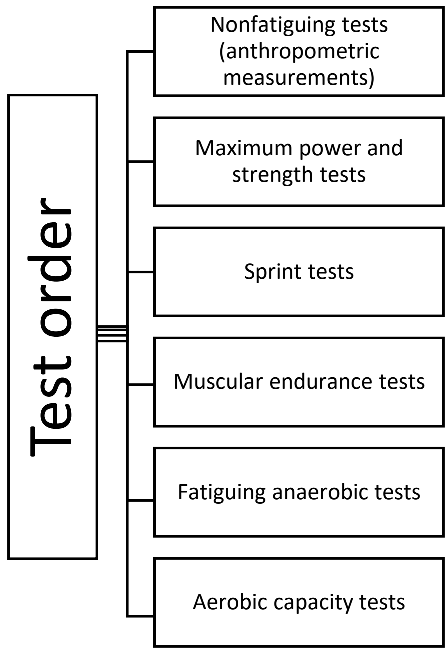

Figure 2. 1 Optimal ordering of the components of fitness within a testing battery (Harman, 2008).

2.6.3.2 Communication considerations for physical testing battery formation

For those who have less frequent physical activity practices, such as jockeys, Pate (2013) suggests that fitness tests must be administered in an sensitive fashion or they will likely have negative consequences (Pate, Welk, & McIver, 2013). Testing and the communication of results in a sensitive fashion, can conversely play a supportive role in promoting physical activity and fitness practices (Cale, Harris, & Chen, 2014; Silverman, Keating, & Phillips, 2008; Welk, 2017). While jockeys are professional athletes, physical activity and preparation strategies have not been reported in the literature and therefore the method of communication ought to be considered.

While the communication of fitness test results should be sensitive, the effect of communication on outcomes during testing also requires practitioner attention. Research in exercise and science has revealed feedback or knowledge of results can enhance motivation having positive effects on self-efficacy and physiological arousal (Schmidt & Lee, 2013). This is particularly evident in maximal aerobic tests where athletes are tested on two or more occasions. During maximal running tests in both field and laboratory settings, performance feedback to a non-athlete population on running pace and test stage produced superior $\dot{V}O_{2max}$ performance scores (Metsios, Flouris, Koutedakis, & Theodorakis, 2006). In contrast, performance feedback in relation to distance has negative outcomes on performance in endurance based cycling time trials (Nikolopoulos, Arkinstall, & Hawley, 2001). This research shows when the distance parameters were hidden from participants, there was a significant improvement in cycling times. The population, while well trained, were small (n=6). Power output was maintained for time trials of 34, 40 and 46 km when the distance of the trial was not revealed. When a control group were informed of the longer distance cycle (46 km), the power output decreased by 13 watts. It is therefore suggested that feedback may alter an athlete's perception of an event so that perceived distance and not actual distance were responsible for changes in power output (Paterson & Marino, 2004).

2.6.4 Validity in a test battery

Three types of validity are commonly applied by researchers in human performance (Currell & Jeukendrup, 2008). These are 1) logical validity that assesses whether a test truly measures what it intends to; 2) construct validity refers to the ability of the measure to distinguish between groups (i.e. novice and elite) and, 3) criterion validity relates to a specific standard or criterion (Thomas, Nelson, & Silverman, 2015) and is broken into two validity types; concurrent or predictive validity. Concurrent validity proposes that the performance measure is correlated with competition performance or the gold standard test for the measure of performance while predictive validity is the ability of a test to predict sporting performance (Thomas et al., 2015).

Tests should measure a sport specific variable linking to the physiological and biomechanical aspects of the sport as previously described (Currell & Jeukendrup, 2008). Researchers have developed riding protocols on mechanical riding simulators to test maximum pushing frequency (Wilson et al., 2014b), EE (Wilson et al., 2013) and respiratory metabolic responses (Cullen et al., 2015). Whilst the use of riding simulators has been commonly employed and appears logically valid to report performance parameters of race riding, the validity of the simulator is questioned. From a kinematic viewpoint, jockeys are exposed to significantly greater dorso-ventral and medio-lateral displacement while galloping with real horses versus the displacement a simulator exhibits (Walker et al., 2016b). A comparison of the physiological demands of a riding simulator compared to that of riding a real horse reported a significant difference with respect to the work associated with each riding platform (Ille et al., 2015). The simulated version of riding a horse over obstacles produced a significantly lower peak HR (123 ± 5 $b·min^{-1}$) than that of a real horse over obstacles (175 ± 3 $b·min^{-1}$). Although potentially a safer method of exercise than 'riding out' on a real horse, reduced HR and sympathetic tone are reported on a simulator when compared to riding a horse (Cullen et al., 2015; Ille et al., 2015). It is therefore concluded that simulated riding can only partially replicate the complex physical relationship between horse and rider (Ille et al., 2015). Alternative tests that measure sport specific parameters, as previously outlined, such as strength, strength endurance, flexibility, stability and aerobic capacity should be considered. In conclusion, based on the current evidence, a mechanical simulator does not appear a valid measure of riding performance with no research to the author's knowledge published using manual (non-motorised) simulators. Instead, valid tests that measure sport specific parameters of performance must be identified and implemented within a larger testing battery design.

2.6.5 Reliability in a test battery

Reliability statistics are generally applied by researchers for one of two reasons; 1) an estimation of the required sample for an experimental study or 2) to estimate the magnitude of individual differences (Hopkins, 2000). Reliability refers to the reproducibility of testing results over two or more testing occasions and warrants attention within sports medicine and exercise science (Boddington, Lambert, Gibson, & Noakes, 2001; Hopkins, 2000). This magnitude of meaningful worthwhile change is often so small in human performance, that the reliability and sensitivity of sport performance measures are critical (Currell & Jeukendrup, 2008).

ICC is the most commonly cited reliability test and is unbiased for any sample size but it has been encouraged that it should not be the only statistic employed (Atkinson & Nevill, 1998; Hopkins, 2000). Within subject variation is proposed by Hopkins (2000) as the most important reliability measure. While numerous statistical tests can investigate types of variation, the most important outcome measures are argued to be typical error and the change in mean between trials (Hopkins, 2000). Typical error can come from various sources but is frequently associated with biological status (Hopkins, 2000). When all participants of a trial are homogeneous, displaying similar values, the typical error can be taken as the same for all participants (Hopkins, 2000). In the context of forming a physical testing battery, practical considerations to improve reliability are presented below from both a biological and technical perspective.

2.6.5.1 Reliability and biological error

In test-retest study designs, measures of reliability often include a percentage coefficient of variation and typical error. Typical error, also known as the standard error of measurement, investigates the random variability of an individual's score on repeat measurements which can be due to variation in either or both biological and psychological status of the athlete. The statistics employed for reliability studies with two trials is straightforward; the typical error can be calculated from the standard deviation of the difference between scores for each participant for two trials. For three or more trials it is proposed that researchers should test consecutive pairs of trials to detect if a learning effect has occurred (Hopkins, 2000). Typical error has been previously used to determine true individual change in physical performance research with the magnitude of those individual changes also reported (Astorino & Schubert, 2014; Bonafiglia et al., 2016).

Practical considerations to reduce biological error should be implemented. Firstly, feedback should be consistent and common to all testing trials in repeated trial studies. Both mental and physical state can induce biological error (Hopkins, 2000) and thus motivation may affect testing scores. While some researchers provide encouragement (Lubans et al., 2011), it is predominantly advised that no encouragement, feedback or performance related data are communicated until all trials are completed (Currell & Jeukendrup, 2008). Secondly, the timing of tests should be kept regular and consistent across all testing occasions with adequate rest periods between trials and exercises. It has previously been recommended that testing should not take place within two days of competition to minimise the effect of fatigue on test outcomes (Turner et al., 2011).

Acknowledging that aerobic endurance, anaerobic power and strength can improve throughout the day, a set time in the evening may be best for accurate reporting of performance parameters while also accounting for variation in circadian rhythm (Gondin, Guette, Ballay, & Martin, 2005; Teo et al., 2011). In summation, the testing sequence, the testing environment and performance feedback can significantly influence performance testing outcomes. With a population such as jockeys with little perceived experience of performance testing, the simplicity of the testing battery should be deliberated in the design phase of any testing battery while testing should be completed where possible on a non-racing and working day.

2.6.5.2 Reliability and technical error

Researchers and practitioners should use the same testing equipment for test-retest which may limit typical error to changes in biological or psychological state (Hopkins, 2000). When testing the reliability of a protocol both the standard error of measurement (Copay, Subach, Glassman, Polly, & Schuler, 2007) and standard error of the mean have been reported. The standard error of measurement is directly related to the reliability of the test (Hopkins, 2000), whilst the standard error of the mean estimates how repeated measures using the same testing instrument are distributed around the individual's true score. The standard error of the mean is related to the population and is utilised to calculate the standard deviation of error, of the sample mean, as an estimate of the population mean (Copay et al., 2007).

It is important that practitioners implement a protocol that is both repeatable and reliable and use devices where technical error is tested and accounted for. When reporting the athlete's results, the standard error of mean should be displayed if the results are to be representative of a larger population.

2.6.6 Summary of validity and reliability

Tests which form part of a physical testing battery should be valid and reliable to measure the related performance outcome, to a certain degree of accuracy (Currell & Jeukendrup, 2008; Thomas et al., 2015). While validity is argued as the most important consideration in fitness testing, an investigation of reliability to distinguish population sample size and/or to explore the magnitude of individual mean differences over repeated trials is warranted (Hopkins, 2000). Variables such as technology, testing equipment and biological status can influence test reliability so the sensitivity of testing to determine the magnitude of meaningful change is critical for researchers and practitioners.

No reliable or valid testing battery is available for use by practitioners working in the horse racing industry. While horse riding simulators may be deemed logically valid by researchers, logical validity is reported to be difficult to assess (Thomas & Nelson, 1990) and is used less frequently in research with more objective measures of validity preferred (Thomas et al., 2015). In addition, research in horse racing has not displayed criterion or construct validity concerning horse racing simulators to measure jockey performance. While individual performance parameters including power, strength, balance, flexibility and pushing frequency have been reported for jockeys (Hitchens et al., 2011a; Wilson et al., 2014b) variation in test methodology, equipment and test sequencing prevent the collection of normative data for the population. A reliable and valid physical testing battery, which outlines test sequencing, apparatus and methodology is therefore required for the industry to reliably profile jockey fitness and to monitor the success of fitness based interventions among the jockey athlete population. In the formation, development and implementation of a testing battery, attention should be paid to both validity and reliability.

2.7 Summary of literature review

The aim of the current review was twofold; firstly, to provide a summary of the physiological demands of racing and the current physical preparation strategies of jockeys. Secondly, the review aimed to provide a theoretical understanding around the reliability and validity of both physiological monitoring tools and physical testing assessments that could be applied by practitioners in a horse racing environment. Despite its popularity as a sport, the review illustrates the complex nature of competing as a professional jockey. While research is frequently assessing jockey health and injury, the relative physiological demands of horse racing remain largely unknown, thereby creating challenges when attempting to prescribe specific training guidelines in preparation for competition. As outlined, alternating variables such as race length, horse temperament and environmental factors have not been thoroughly investigated and warrant consideration to fully establish the physiological demands of racing. To investigate racing demands, the review highlights that HR monitoring, blood lactate monitoring and rate of perceived exertion provide three reliable modalities to measure the physiological demands in a competitive environment for professional jockeys.

The current review revealed a paucity of information concerning the physical preparation strategies of jockeys which limits the potential for scientific and race specific performance interventions. Due to the dearth of scientific research relating to jockey's physical preparation strategies it remains to be determined if jockeys participate in additional physical exercise to improve physical conditioning and enhancing riding performance. Additionally, there is no reliable testing battery in existence nationally or internationally to evaluate jockey fitness. An understanding of the preparation strategies and a physical performance testing battery will enable practitioners to design, plan and evaluate sport specific training interventions. Considering the findings of this review and the presented gaps in the literature, the overall aim of the thesis was to investigate the demands and preparation strategies of professional jockeys while developing a physical testing battery for the horse racing industry.

Chapter Three: Physiological and performance monitoring in competitive sporting environments: A review for elite individual sports

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3.1 Preface

Chapter Two reviewed the available literature in horse racing and the complexity of a jockey's lifestyle. In greater detail the physiological demands and environmental factors which may affect the physiological responses of the jockeys were presented. A paucity of data on the demands placed on jockeys over specific race distances were identified. While it has been suggested that both the aerobic and anaerobic energy systems contribute to the energy demand of race riding (Cullen et al., 2015; Trowbridge, 1995), there is a dearth of data on blood lactate concentration post racing. Athletes are commonly assessed using a variety of physiological monitoring methods to estimate appropriate training load, screen for overtraining and to empower coaches to match training with the physiological demands of the sport (Kraemer et al., 2009; Li et al., 2016; Taha & Thomas, 2003). The current chapter reviews a variety of objective and subjective physiological monitoring tools. Furthermore, this chapter identifies valid and reliable monitoring devices which can be implemented in elite and competitive sport settings for individual athletes and therefore fulfilling objective one of the thesis. The findings formulated in this chapter provided information on robust physiological monitoring tools which were utilised for data collection in Chapter Five.

3.2 Abstract

There is a great appreciation for the application of physiological monitoring within competition for individual sports. Physiological monitoring allows feedback on exercise dose-response, exercise intensity, and exercise performance. Both subjective and objective parameters are commonly measured in the field sports, but research investigating the accuracy and applicability of monitoring tools in a competitive environment for individual athletes is limited. This narrative review highlights the strengths and weaknesses of individual devices to measure a variety of parameters, including physiological performance, and biochemical and subjective parameters. Based on an analysis of the existing scientific literature, practical applications are provided for coaches.

3.3 Introduction

Athletes are commonly assessed using a variety of physiological and performance monitoring methods to estimate appropriate training load, screen for overtraining and to empower coaches to match training with the physiological demands of the sport (Kraemer et al., 2009; Li et al., 2016; Taha & Thomas, 2003). Individuals can respond differently to the same training or competition stress despite similarities in age, race, sex and current level of fitness (Borresen & Lambert, 2009; Skinner et al., 2001). Excessive physical stress induced during training and competition can result in disturbances of peripheral and central responses such as muscle soreness, mood state, biochemical markers and neural response times (Lehmann et al., 1993). Thus, individual monitoring of training and competition dose response is paramount for jockeys in competitive races. The monitoring of athlete activity and training load can provide essential information as to whether an individual is meeting or exceeding optimal functional levels of stress during training and competition (Scott, Lockie, Knight, Clark, & De Jonge, 2013a). Monitoring can also inform athletes, coaches and support staff on how best to alter training practices to meet competition demands (Li et al., 2016).

Several modalities to assess physiological and performance characteristics exist including external and internal values (Scott et al., 2013a). Internal values require quantification of the physiological stress placed on the athlete with the most common methods to measure exercise intensity by way of HR various blood biomarkers and a rating of perceived exertion (RPE) (Currell & Jeukendrup, 2008; Scott et al., 2013a). External values of training and competition utilise metrics such as power output via jump performance or distance covered (meters) (Wallace, Slattery, & Coutts, 2014). Physiological (Li et al., 2016), biochemical (Vangelakoudi et al., 2007), subjective measures (Scott, Black, Quinn, & Coutts, 2013b) and jump performance (Suzuki et al., 2006) are all potential parameters for individual athlete monitoring however their use in competition remains unclear and sparsely researched.

Difficulties arise when monitoring sports performance during competition due to a variety of constraining factors including rules and regulations, environmental conditions and individuality of dose response mechanisms within athletes. Sports such as horse racing and combative sports have strict weight restrictions imposed (Dolan et al., 2011; Leydon & Wall, 2002; Tsai, Ko, Chang, Chou, & Fang, 2011) which may prohibit the use of monitoring devices which add additional weight. Environmental conditions including the perceived importance of the competition in which athletes perform may also have an influential physical, motivational or physiological effect (Hopkins, 1991). Although physiological load in high intensity sports has proven difficult to quantify (Foster et al., 2001), technological advances in equipment design have facilitated tracking activity profiles in sport common practice (Aughey, 2011; Aughey & Falloon, 2010; Bangsbo, Mohr, & Krustrup, 2006). Functional tools that incorporate physiological feedback are required to guide training programme design by determining both dose response and intensity of effort during competition (Li et al., 2016). Obtaining physiological data has become more attainable with the introduction of modern technology such as lightweight HR monitors, accelerometers, GPS units and integrated technology which has enabled sports scientists to take physiological performance testing from the laboratory to the field (Larsson, 2003; Li et al., 2016). The following section will present and analyse a variety of tools to monitor exercise performance in competition.

3.4 Heart rate monitoring

While HR has been monitored extensively among individual athletes in competition (Rincon, Turco, Martinez, & Vaque, 1992; Schwaberger, 1987; Sperlich et al., 2012) there is a paucity of scientific literature relating to the monitoring of other physiological parameters in competition. HR monitors are an accessible and non-invasive tool (Sperlich et al., 2012), primarily used to record mean and peak HR (Hernando, Garatachea, Almeida, Casajús, & Bailón, 2016). While some individual sports show a large degree of HR variability between and within competition, real time monitoring is important to estimate the acute physiological load of the event imposed on the participant (Padilla et al., 2001). HR is commonly used to measure exercise intensity by way of a strap fitted in line with the sternum (Jeukendrup & Van Diemen, 1998). Electrodes placed on the chest show a mean bias and variability of less than one beat per minute (Léger & Thivierge, 1988). HR devices have been validated to measure low and high intensity exercise (Hernando et al., 2016). Of the most common and most accurate brands, Polar has been reported as a reliable tool to report mean HR (Hernando et al., 2016; Laukkanen & Virtanen, 1998).

Several studies have utilised HR data in competitive and individual sporting environments. On and off road competitive cycling (Sperlich et al., 2012; Viru & Viru, 2000); horse racing (O'Reilly et al., 2017; Trowbridge et al., 1995); Olympic horse riding (Rincon et al., 1992); competitive sailing and motorsport (Collins, Reilly, & Morton, 2014; Schwaberger, 1987) are just some of the individual athlete sports that have used HR as a measure of intensity in competition (Table 3.1). While external environmental factors such as temperature and altitude can affect HR (Hamilton et al., 1991), competition stress must also be considered. Increased secretion of epinephrine during periods of high concentration and technical precision is evident among professional badminton players (Cabello Manrique & González-Badillo, 2003). This increased hormonal reaction may instigate an elevated HR response, more than what is required by the actual physical effort. Although specific consideration must be given to competition requirements and environmental factors as aforementioned, HR monitors are perceived user-friendly, reliable and valid to measure exercise intensity response.

3.5 Accelerometers

The use of accelerometer based devices has seen a positive advancement in research (Dellaserra, CL, Gao, and Ransdell, 2013) with sampling frequencies up to 100 Hz available from devices (Troiano, McClain, Brychta, & Chen, 2014). Accelerometers measure movement of direction in uniaxial and tri-axial planes to indicate frequency, duration and intensity of activity (Butte, Ekelund, & Westerterp, 2012; Chen & Bassett, 2005). Significantly improved estimations of energy expenditure (EE) have now also been developed with raw acceleration data preferred over counts data (Troiano et al., 2014) which tracks the number of times an activity reaches the desired activity threshold. The application of accelerometers has been used in individual sport to estimate EE (Wilson et al., 2013), exercise intensity and the analysis of skill in sports such as swimming (counts data) (Davey, Anderson, & James, 2008) and tennis (raw acceleration data) (Ahmadi, Rowlands, & James, 2009).

Accelerometers have been reported to be a valuable tool for activity measurement in many individual sports including equine (Wilson et al., 2013), swimming (Callaway, Cobb, & Jones, 2009; Davey et al., 2008), and tennis (Ahmadi et al., 2009). Validity studies in physical activity have indicated moderate to strong correlations between oxygen consumption and accelerometer counts ($r = 0.45$-93) (Trost, Mciver, & Pate, 2005). However, counts data fails to distinguish between types of activity with particular problems identified in activities such as cycling and weightlifting where the intensities reported do not match the movement context of the activity (Matthews, 2005). Raw acceleration data for sports is thus preferred.

The application of accelerometers for the calculation of exercise intensity and EE includes a number of limitations accompanied by analytical challenges (Troiano et al., 2014). Comparability of data collected from sensors worn on different parts of the body is a concern due to weak correlations for exercise intensity and EE (Swartz et al., 2000; Troiano et al., 2014). There is also a greater cost and time requirement for the analysis of data when using wrist worn accelerometers due to the regression equations required to explain the variance of metabolic cost when recording activity intensity from other body sites (Swartz et al., 2000). Further inadequacies exist with varying thresholds and algorithms used in the calculation of intensity by each manufacturer (Troiano et al., 2014). Accelerometers are a valid tool to measure low intensity exercise however, limitations exist with regard to high intensity movements and EE calculations for high intensity sports. With high intensity efforts reported in horse racing (Cullen et al., 2015; Trowbridge et al., 1995), accelerometers may not be a reliable tool.

3.6 Integrated technology

The Equivital life monitor EQ02 (EQ02; Hidalgo, Cambridge, United Kingdom) is a combination of sensors worn on a chest strap that reports HR, thermal status, respiratory rate via chest expansions and motion through a tri-axial accelerometer. The lightweight device is novel and is capable of storing and transmitting real time physiological and psychophysiological data for up to 50 days (Liu, Zhu, Wang, Ye, & Li, 2013). The Equivital has been reported as a valid and reliable tool for the ambulatory monitoring of physiological responses (Liu et al., 2013). Liu et al. (2013) presented strong correlations between HR, respiratory rate, skin temperature and core temperature using the Equivital tool while EE calculations can also be estimated. The Equivital has been utilised in individual competitive sporting environments to monitor jockeys (Cullen et al., 2015); however to measure EE with this device requires a pre-examination step test which may not be suitable for elite athletes. Research cost is an additional limitation of this device as neither the dermal patch or Jonah pill, an ingestible capsule, are reusable and therefore make the Equivital an expensive research tool (Liu et al., 2013). In conclusion the Equivital is a reliable and valid tool for the recording of low intensity activities (Akintola, van de Pol, Bimmel, Maan, & van Heemst, 2016).

The Actiheart monitor (Actiheart, Cambridge Neurotechnology Ltd, Cambridge, UK) measures EE via combined HR and motion analysis and can record physical activity data for up to 21 days. The Actiheart device weighs 10g and with an internal rechargeable battery, it provides a light weight device to measure physical activity and EE (Chen & Bassett, 2005). The device is generally worn on the chest using ECG pads (Brage, Brage, Franks, Ekelund, & Wareham, 2005). Although HR can be utilised to indicate EE, combining HR and motion analysis may improve the accuracy of EE calculations (Brage et al., 2003; Spierer, Hagins, Rundle, & Pappas, 2011). The Actiheart is deemed a valid and reliable tool to measure EE when walking and jogging (Brage et al., 2005). Although it has been utilised among individual athletes (Wilson et al., 2013), it was deemed inaccurate when measuring higher intensity sport as found with both male and female basketball players (Santos et al., 2014).

To improve the accuracy of data analysis, Spierer et al. (2011) proposed that devices are individually calibrated. The accurate measurement of HR and motion analysis is critical to investigate dose response relationships of exercise in competition. As with other devices, the placement of accelerometers may affect the reliability of data obtained. It has been presented that the Actiheart accelerometer underperforms in comparison to other accelerometer devices placed around the hip area with particular reference to higher intensity activity such as level jogging (Spierer et al., 2011). To limit error, the device is best placed underneath the sternum like Polar devices (Brage et al., 2003) where less contact may also be experienced in individual sports of a contact nature. A valid and reliable device for low intensity activities, further validation is required with elite athletes in high intensity sport and it is proposed that it would not be suitable in horse racing.

The Sense Wear Pro 3 armband (Body Media, USA) is a multi-functioning device worn on the upper arm that can measure heat production, biaxial acceleration and EE (Sperlich, Koehler, Holmberg, Zinner, & Mester, 2011). The multi-sensor device consists of a heat flux sensor, galvanic skin response sensor, a skin temperature sensor and a near body ambient temperature sensor (Liden et al., 2002). Using a 1-minute epoch, the device is capable of collecting and storing physiological data up to 5.5 days (Chen & Bassett, 2005). Previous studies has validated the arm band to estimate EE in low to moderate free living activities (Drenowatz & Eisenmann, 2011; Fruin & Rankin, 2004; Liden et al., 2002), however, it was recently found that the arm band underestimates EE when stepping, walking and jogging (Jakicic et al., 2004; Sperlich et al., 2012). The arm band design makes it light weight and suitable to be worn in many sporting environments, however, prior to data collection, it is suggested by the manufacturer that participants remain in a seated position for a 15 minute familiarization period (Jakicic et al., 2004). This would not be possible in many competitive sporting environments where warm-ups are prescribed before the main event including horse racing. It is unknown if the device would be reliable outside of the laboratory in environments which require high intensity exercise (Jakicic et al., 2004; Powell, Carson, Dowd, & Donnelly, 2016).

In summary, the literature surrounding HR, accelerometers and integrated technology is dominated by two domains; low intensity physical activity research in normal populations and elite male athletes in various football codes (Cummins et al., 2013). Much research is therefore required in high intensity activities and individual sports.

Table 3.1 Summary table of physiological monitoring tools reported from competition in elite Individual sports.

Parameter measured	Device	Research reported from	Advantages	Disadvantages
Heart Rate	**HR monitor**	Road cycling, Off Road cycling, Horse racing, Olympic horse riding, Competitive sailing, Motor sport	Validated to measure low & high intensity exercise. Commonly used in competition & individual sporting environments.	Temperature and hydration status may affect readings. Prolonged isometric efforts can elevate HR.
Frequency & magnitude of movement	**Accelerometer**	Equine, Swimming, Tennis	Validated to measure low intensity exercise. Have been utilised to assess sports skills such as tennis and swimming strokes.	A number of algorithms exist which make comparability of data difficult. Unable to distinguish between different types of activity. Not suitable for high intensity activities.
HR, respiratory rate, skin temperature and core temperature	**Equivital**	Horse racing	Reports data for up to 50 days. Light weight device.	Has not been validated in sporting environments. Elements of the device are not reusable which may elevate research costs. The device is fitted with a generic sized belt.
EE via combined HR and motion analysis data	**Actiheart**	No research is available from competition with Individual sport athletes.	Valid & reliable tool for activities of low intensity. Lightweight device. Contains a rechargeable battery.	Individual components of the device must be calibrated individually. Not suitable for high intensity activities.
Heat production, biaxial acceleration and EE	**Sensewear Pro 3 arm band**	Table tennis	Can store data for up to 5 days. Lightweight device.	Not suitable for high intensity activities and a 15-minute familiarization period is required with the athlete prior to the event.

3.7 Blood lactate concentration

Blood lactate concentration values have been previously recorded as an indicator of metabolic fatigue in individual sports in elite and sub-elite categories (Faude, Kindermann, & Meyer, 2009; Urhausen, Gabriel, & Kindermann, 2002; Vangelakoudi et al., 2007). In addition to monitoring fatigue, blood lactate has been used to analyse longitudinal fluctuations in aerobic and anaerobic fitness (Faude et al., 2009). The Lactate PRO (Akray, Japan) is a device which has outperformed a large number of analysers when compared to the criterion enzymatic method (Baldari et al., 2009; Goodwin et al., 2007; Pyne, Boston, Martin, & Logan, 2000).

The sites from which blood is measured (ear lobe, fingertips, venous) as well as the device and blood sample, can affect the test results (Faude et al., 2009). The Lactate PRO does not require pipetting of blood, which reduces the chance of experimental error, while only a small blood sample of 5µl is required on the reagent strip for analysis. In terms of accuracy of site samples, samples taken from the earlobe have consistently shown lower blood lactate concentration than samples taken from the fingertip (Faude et al., 2009). However sufficient concentrations at both sites deem the lactate PRO and the newer lactate plus, a valid and reliable tool to measure lactate concentration in all sporting disciplines (Pyne et al., 2000; Tanner, Fuller, & Ross, 2010). As many sports require frequent use of the hands with some athletes required to wear gloves, lactate samples taken from capillary blood by a hyperaemised ear lobe is a common field approach (Collins, Doherty, & Talbot, 1993; Hopkins, 1991; Pyne et al., 2000). While lactate can rise progressively during an incremental test to volitional exhaustion or an exercise bout, peak lactate values are generally seen between 3-8 minutes post event (Goodwin et al., 2007). As with other physiological tools external and internal environmental factors need to be considered (Borresen & Lambert, 2009). Furthermore, practitioners must note that if comparing sports, the mode of exercise can affect lactate accumulation due to alterations of muscle mass (Svedahl & MacIntosh, 2003) as would be seen between running and cycling. If comparing individual athletes within the same sport, training status and training load have both been proposed to affect maximal and submaximal lactate concentrations (Jeukendrup & Hesselink, 1994; Urhausen, Gabriel, Weiler, & Kindermann, 1998) and therefore must be considered during data collection.

3.8 Subjective monitoring

The most widely accepted subjective tool for the assessment of physiological responses to training and competition is RPE using the Borg (6-20) scale (Borg, 1982). Foster et al (2001) developed an extension of the RPE method which was entitled the session RPE (sRPE) method (RPE score of a session (1-10) x duration in minutes). The sRPE approach is now considered a common standard method of calculating perceived effort and load (Day, McGuigan, Brice, & Foster, 2004). It is proposed that this modification of the Borg ratio 10 scale (CR10) (Borg, 1982) may be a more effective method to calculate exercise intensity and the subjective physiological load of an event. However recent evidence suggest both scales, while providing different absolute numbers can be used interchangeably with very strong relationship presented for incremental (R^2=0.89) and interval exercise (R^2=0.89) (Arney et al., 2019).

sRPE is an accurate tool to minimise undesired training effects and is a proven subjective approach to quantify exercise intensity (Day et al., 2004; Herman, Foster, Maher, Mikat, & Porcari, 2006). For both endurance and high intensity intermittent sports, the sRPE method of calculating training load and training intensity is considered a valid and reliable measure (Foster et al., 2001; Lupo, Tessitore, Gasperi, & Gomez, 2017) with an intraclass correlation coefficient (ICC) of 0.88 when investigating high, moderate and low intensity sessions (Day et al., 2004; Herman et al., 2006). Additionally sRPE is a sensitive tool which can detected accumulated fatigue over time (Fusco et al., 2020b). sRPE correlates closely with internal measures of training load (Cormack, Newton, & McGuigan, 2008; Foster et al., 2001) along with objective measures of training intensity including HR and blood lactate concentration (Herman et al., 2006; Serrano, Salvador, González-Bono, Carlos, & Ferrán, 2001).

The sRPE method of calculating training intensity has been a proven methodological approach in a training environment with individual athletes for some time. Recent research has validated its use in a competition environment with professional cyclists (Van Erp, Foster, & Koning, 2019). There are few limitations presented in the research but Wallace, Slattery, & Coutts (2014) and Scott et al. (2013b) recently reported a high measurement error when reporting with a 0-10 RPE scale for long and short bouts of running with a large coefficient of variation in comparison to HR data. It is also known that duration can effect perceived exertion despite internal and external load measures (Fusco et al., 2020a). Further research of the sRPE method in competitive environments is warranted to determine its validity in reporting competition related stress in athletes. From a practical perspective, athletes should submit RPE scores in isolation to avoid any selection bias based on other athlete's scores. Furthermore, athletes should submit their RPE score after acute fatigue has dissipated, as the score may be reflective of the last exertion rather than a score reflective of the session intensity as a whole. Between 10 and 30 minutes is recommend after exercise for reporting RPE scores (Sweet, Foster, McGuigan, & Brice, 2004).

While sRPE or RPE has not previously been used in horse racing, research proposes that the reporting method is reliable to measure both steady state and high intensity efforts (Foster et al., 2001). Jockeys may not be accustomed to reporting perceived exertion with no previous research undertaken with the athlete population, however research shows familiarity with the scale does not affect scores (Chen, Chen, Hsia, & Lin, 2013).

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3.9 Summary of monitoring devices

While many monitoring devices provide informative data, the practitioner must consider their applicability in a chosen environment. For devices to be effective in an elite setting, the monitoring tool must be user friendly and time efficient while also ensuring it does not negatively affect the athlete's pre-performance routine. If the device is to be worn during completion, the coach should ensure the device is comfortable for the athlete and it is permitted to be worn by the regulatory authorities. Devices which provide the practitioner with pre-and post-event measures such as those discussed under the heart rate, biochemical and subjective monitoring sections and can provide the coach with valid data. A knowledge of the competition requirements should, however, underpin physiological and performance monitoring to ensure practitioners collect data, which is consistent over multiple time points in a competition setting. It is advisable that coaches document the exact protocols that they will use in each testing session to ensure a standardised and comparable monitoring environment is created. This is also applicable to subjective measures such as sRPE.

Practitioners must also be cognisant of implications involving the individuality of an athlete particularly regarding variations in exercise dose response. It is important that coaches are aware of these variations when performing data analyses and data comparisons on a number of individual athletes. Internal and external factors such as hydration status, nutritional and medicinal intake, climate and psychological status should be noted both in preparation for and during the competition to provide background information on the data. Such an approach will ensure that results from one monitoring session may be compared with subsequent or previous data to assess if any meaningful worthwhile change has ensued.

Chapter Four: Physical Preparation Strategies of Professional Jockeys

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4.1 Preface

The previous chapters offered a review of the literature and narrative review with evidence presented of unhealthy weight making practices in addition to a paucity in the literature surrounding physical activity and physical preparation strategies of jockeys. While it is understood jockeys have riding and work duties in addition to racing (Labadarios et al., 1993), training activities or strength and conditioning practices are not established in the literature. Chapter four contains the first empirical research study. The research study was framed in the context of exploratory research rather than a prominent hypothesis and investigated the physical preparation strategies of 85 professional jockeys. The research is divided into four sections detailing background information, body mass loss and exercise habits associated with making weight, current physical activity habits and jockey's perceptions and practices of S&C. Daily 'riding out' performed by jockeys is described as having a steady state aerobic demand and is suggested to be insufficient to meet the demands of racing (Kiely et al., 2019a). This highlights the importance of performing additional high intensity training (Kiely et al., 2019a). Aligned with the aim and second objective of this thesis, the chapter illustrates both physical activity levels and preparation strategies of professional jockeys. The detailed findings on physical preparation strategies and exercise habits address a gap in the current literature and additionally a gap between theory and best practice for professional athletes in meeting the physiological requirements of their sport. The findings also propose that jockeys may not be equipped to meet the demands of racing identified in the current literature. A greater understanding of these demands relative to race distance will be presented in Chapter Five.

4.2 Abstract

Professional horse racing is a physically demanding sport. The aim of the study was to examine the physical preparation strategies of jockeys for racing. A questionnaire was developed and validated which comprised of 4 sections: (a) background information, (b) making weight and current associated exercise habits, (c) current physical activity practices, and (d) jockey perceptions of strength and conditioning (S&C) and current practices. Eighty-five jockeys (n=38 professional flat, n=47 professional NH) completed the questionnaire in race course weighing rooms representing 80% of the professional athlete population. In total 77.6% of jockeys participate in physical activity outside of riding. Jockeys that participated in S&C (42.4%) reported their most frequent type of S&C practice; cardio (52.8%), high intensity interval training (33.3%), flexibility & mobility training (8.3%), resistance training (5.6%). There was no significant difference in S&C participation between total flat and total NH licenses (p=0.530; [PHI] =0.068). Difficulty making weight was reported by 55.3% of jockeys. Exercise alone was utilised by 29.4% of jockeys to rapidly reduce weight. There was no significant difference (p=0.201, [PHI] =0.357) between the frequency of rapid weight loss per month for total flat (1.7 ± 1.7) and total NH jockeys (1.6 ± 0.5). This study represents the only published data on the physical preparation strategies of jockeys. Jockeys do not partake in physical activity, which mimics the repeated high intensity demands of racing, nor do they frequently participate in S&C practices. Future research is required to examine the effects of specific S&C interventions on riding performance.

4.3 Introduction

Horse racing has been identified as a physically demanding sport (Cullen et al., 2015; Trowbridge et al., 1995). Jockeys partake in either flat racing or NH racing, which take place over jumps. Each license type consists of two sub categories; professional flat license or apprentice flat license (less experienced) and professional NH license or conditional NH license (less experienced). Flat racing is held over course distances of 1,000-3,000 m with pre-race weight requirements of 52.7 to 64.0 kg. National hunt racing also known as NH racing takes place in course distances ranging from 3,200 up to 7,000 m. Jockeys can afford to be heavier in this category with the weight requirement ranging from 62 to 76 kg (Cullen et al., 2015). As jockeys must exercise close to their physiological capacity (Cullen et al., 2015; Trowbridge et al., 1995), while maintaining low body mass, high levels of aerobic and anaerobic power are required to be successful (Cullen et al., 2015). Currently, licenced jockeys may be required to compete multiple times a day, up to 7 days a week, with no specific off-season (Dolan et al., 2011). In preparing jockeys to meet the demands of racing, it would be expected that jockeys experience faster recovery rates by reducing fatigue between races. In addition, a greater aerobic capacity may reduce the risk of falls and resulting injury (Hitchens et al., 2010; Wilson et al., 2015). Daily 'riding out' has previously been suggested to be insufficient to meet the physiological demands of racing, highlighting the importance of performing additional training (Kiely et al., 2019a).

Several studies have investigated strength and conditioning (S&C) training practices, across a range of sports including swimming (Bishop et al., 2013); American football (Ebben & Blackard, 2001); baseball (Ebben, Hintz, & Simenz, 2005); rowing (Gee et al., 2011); and Rugby union (Jones, Smith, MacNaughton, & French, 2016; Weakley et al., 2017). These studies provide a comprehensive overview and insight of current S&C practices in addition to providing a reference point for applied practitioners (Jones et al., 2016). In addition to sports performance benefits, there are positive effects of resistance training on health-related measures including body composition, bone health and a reduction in sports related injuries (Faigenbaum et al., 2009). Despite the associated benefits, it is unknown if jockeys complete basic and less complex weight training or indeed complete any S&C practices in addition to their daily 'riding out'.

Gaining an understanding of jockey's current physical preparation strategies for racing will allow coaches and governing authorities to facilitate specific training modalities with appropriate physiological demands to optimally prepare jockeys for racing. Subsequently, quantifying typical jockey physical training practices will allow coaches and jockeys alike to plan for optimal performance and individualise training regimes (Foster et al., 2001; Scott et al., 2013b). Therefore, the aim of the study was to investigate the current physical preparation strategies of jockeys during the racing season.

4.4 Methods

4.4.1 Experimental Approach to the Problem

A questionnaire was devised to explore the training habits and preparation strategies of professional jockeys. The questionnaire was broken into 4 sections comprising a total of 27 questions and was circulated to professional jockeys in person at various racecourse-weighing rooms. Prior approval for the study was granted by the Irish Horse Racing Regulatory Board, the regulatory authority for Irish horse racing. Ethical approval for the study was obtained from the third level institutions review board of research compliance and all procedures were in accordance with the Declaration of Helsinki.

4.4.2 Participants

Eighty-five professional jockeys participated in the study (n=3 female, n=82 male). Participants included 38 professional flat jockeys (professional n=16; apprentice n=22) and 47 professional NH jockeys (professional n=27; conditional n=20). A priori power analysis indicated that a total of 52 participants would be needed to have 80% power for detecting a large sized effect (d=0.8) (Faul, Erdfelder, Lang, & Buchner, 2007). All participants were informed that their participation in the study was voluntary. Informed consent documents were signed and gathered for all participants prior to completion of the questionnaire (see appendix C).

4.4.3 Procedures

The questionnaire was circulated to jockeys at race courses along with an introductory letter explaining the aims and objectives of the proposed research study. Race meetings were attended and questionnaires were filled out using a semi-structured interview style by the same researcher for consistency and to clarify any ambiguities. This questionnaire was completed in the jockey weighing room before and between races at the jockey's convenience. At the time of completing the questionnaire, NH jockeys were at the end of their season while flat jockeys were at the beginning of their season.

Questionnaire. The questionnaire entitled, "The physical preparation strategies of professional jockeys", template was developed by the research team through a commercially available online questionnaire generator (Survey Monkey Inc., San Mateo, California, USA) and included 27 questions incorporating open and closed ended questions. The self-designed questionnaire was divided into 4 sections:

1) Background information; this section detailed information on personal demographics, individual licensing, racing and working commitments.
2) Making weight and current associated exercise habits; the aim of this section was to identify the prevalence and magnitude of rapid weight loss which was defined as weight lost over a period equal to or less than 24 hours. In addition, the utilization of exercise as a weight loss tool was investigated.
3) Current physical activity habits; the objective of this section was to quantify and describe jockeys exercise patterns outside of riding related work. Perceptual load of each exercise session was calculated using the Session "Rate of Perceived Exertion" (sRPE) Method. These sessions referred to exercise sessions outside of riding related activity that jockeys recalled as a weekly occurrence throughout the racing season. sRPE was calculated by multiplying the intensity of the sessions (Borg CR-10 scale) by the session duration in minutes to form arbitrary units (AU).

4) Practice and perceptions of S&C; the aim of this section was to gain an understanding of jockey's knowledge, practice and preferences surrounding S&C in addition to S&C services they would like provided. For the purpose of data collection and analysis, S&C was defined as any specific physical training that was utilised to improve riding performance outside of riding related work. Physical activity was defined as any exercise completed where the aim was not improving riding performance.

To validate the questionnaire, a two round iterative Delphi consensus method was administered (see appendix A) (Stewart et al., 1999). The questionnaire was circulated via email to 14 individuals with an introductory letter explaining the aims and objectives of the proposed research study and Delphi method. These individuals were selected based upon previous academic publications in the area of jockey health and performance, qualitative research or both. Eleven individuals responded and they were asked to review and score each question on its relevance to the study aim using a 0-10 point (0 = no relevance; 10 = highly relevant) Likert scale (Benhamou et al., 2013). Following analysis of the audit from all individuals, questions were accepted for the final questionnaire with an average of 70% acceptance or greater in line with previous research (Stewart et al., 2017). Questions were rejected from the questionnaire if they averaged 30% or below. Comments from the review panel were welcomed to improve the questions in relation to appropriateness to the study aim. A reoccurring suggestion from two or more of the panel to the wording or format of questions were applied. All questions were accepted following analysis of round one scores and it was not necessary for the questionnaire to enter round two. The experts were sent the accepted questionnaire after this point for final confirmation and approval.

4.4.4 Statistical Analysis

Data were analysed using SPSS (Statistical Package for the Social Sciences V22.0, SPSS Inc, Chicago, Illinois, USA). Descriptive analysis was the primary form of quantitative analysis which was conducted on closed ended questions while thematic analysis was applied to open ended questions. Data were assessed for normality using a Shapiro-

Wilk test and descriptive data were presented as mean and standard deviation (mean ± SD) with a 95% confidence interval (95% CI). A Mann-Whitney U test was administered to research differences between total flat and total NH jockeys for non-parametric data while independent t-tests were administered for parametric data. Effect size (ES) for between group differences were calculated using Cohen's d with *d*=0.2 considered a 'small' ES, 0.5 represents a 'medium' ES and 0.8 a 'large' ES (Cohen, 1988). A one-way anova and tukey post hoc test were administered to investigate if any difference existed between sub categories of the jockey license (flat, apprentice, NH and conditional). A Kruskall-Wallis with pairwise comparisons was used to examine if any difference existed between groups where data were not normally distributed. In this instance, Eta squared was used to quantify ES. To explore if any relationship existed between activity parameters and background information, a Pearson product moment correlation was administered. In the case of two nominal variables, a Pearson Chi squared test of association was administered. A phi coefficient ([PHI]) was used to interpret the strength of association. Statistical significance was accepted at an alpha level of $p \leq 0.05$. Thematic analysis was applied to the open ended questions, following the guidelines set out by Braun and Clarke (2006) which includes six phases: (1) familiarization with the data, (2) generating codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes and, (6) producing the report.

4.5 Results

4.5.1 Background Information

Background information for flat and NH jockeys in addition to a breakdown of license sub categories are reported in Table 4.1. Jockeys were working 34 ± 14 hours weekly in addition to race riding. Professional flat jockeys held their license for greater years and experienced a significantly higher number of winners than other jockeys ($p \leq 0.05$).

Table 4.1 Background data of flat and NH jockeys with a breakdown of license sub categories (n=85).

	Flat Total (n=38)	NH Total (n=47)	Professional Flat (n=16)	Apprentice Flat (n=22)	Professional NH (n=27)	Conditional NH (n=20)	Total (n=85)
Age (years)							
Mean ± SD	24.6 ± 9.2	26.0 ± 5.1	†Δ 31.4 ± 10.6	¥†19.6 ± 2.9	†27.6 ± 5.7	¥23.9 ± 3.4	25.4 ± 7.2
Years licence held							
Mean ± SD	8.2 ± 9.6	8.0 ± 5.4	†Δ 15.4 ± 11.1	¥‡3.0 ± 2.0	†Δ 10.4 ± 5.8	¥‡4.7 ± 2.7	8.1 ± 7.5
Number of races per week	9.4 ± 8.4	6.9 ± 6.3	*16.3 ± 8.7	¥5.9 ± 2.9	¥5.4 ± 3.0	¥3.5 ± 1.8	6.9 ± 6.4
Mean ± SD 95%CI	(6.73, 12.07)	(5.1, 8.7)	(12.0, 20.6)	(4.7, 7.1)	(3.2, 5.7)	(2.7, 4.3)	(5.5, 8.3)
Hours worked per week	29.7 ± 12.4	34.0 ± 14.0	Δ27.7 ± 16	31.2 ± 13.3	35.2 ± 27.0	¥40.6 ± 13.2	34.0 ± 14.0
Mean ± SD 95%CI	(25.8, 33.6)	(30.0, 38.0)	(19.9, 35.6)	(25.6, 36.8)	(25.0, 45.4)	(34.8, 46.4)	(31.0, 37.0)
Number of winners							
Median	214.1 ± 335.1	102.5 ± 174.9	*460 .0	¥7.5	¥95.0	¥14.0	49.0
IQR	(107.6, 320.7)	(52.5, 152.5)	(157.5, 675.0)	(2.0, 36.0)	(64.5, 185.0)	(7.5, 33.5)	(8, 150)

The data are expressed as Mean ± SD 95% confidence intervals (95%CI) or median and interquartile ranges (IQR).*$p \leq 0.05$ significantly different from all sub groups. ¥$p \leq 0.05$ significantly different from professional flat group. ‡$p \leq 0.05$ significantly different from professional NH group. †$p \leq 0.05$ significantly different from apprentice group. Δ$p \leq 0.05$ significantly different from conditional group. The number of races per week represents in season figures while hours worked represents yard and 'riding out' completed independent of racing commitments. The hours worked per week represents riding horses, mucking out stables and yard duties. The number of winners is positively skewed data and the median with interquartile range are presented.

4.5.2 Making Weight and Associated Exercise Habits

Difficulty surrounding weight management was reported by 55.3% (n=47) of jockeys. The typical amount of weight loss (kg) of jockeys prior to racing was significantly different among total flat (1.4 ± 0.6kg, 95% CI; 1.2, 1.7) and total NH jockeys (2.0 ± 0.1 kg, 95% CI; 1.7, 2.3) (p=0.007, ES=1.39 {large}). The differences in license sub categories were located between apprentice (1.3 ± 0.6 kg, 95% CI; 1.1, 1.6) and conditional licenses (2.0 ± 0.7 kg, 95% CI; 1.6, 2.3) (p=0.01, ES=1.07 {large}) and apprentice-professional NH licenses (2.0 ± 0.8 kg, 95% CI; 1.5, 2.4) (p=0.02, ES=0.98 {large}). No relationships existed between age and weight loss amount (r = 0.141; p=0.306).

Sixty-seven percent of jockeys reported that they rapidly lose weight (24-48 hours prior to racing) at least once a month to race. There was no significant difference (p=0.201, [PHI] =0.357) between the frequency of weight loss per month for total flat (1.7 ± 1.7, 95% CI; 1.1, 2.3) and total NH jockeys (1.6 ± 0.5, 95% CI; 1.4, 1.9). A significant association was located between professional flat and professional NH sub licenses (p=0.018, [PHI] =0.710). Mean rapid weight loss frequency for each sub category were; professional flat (1.0 ± 0.5, 95% CI; 0.8, 1.3), professional NH (1.6 ± 0.8, 95% CI; 1.2, 2.1), apprentice (2.2 ± 2.2, 95% CI; 1.1, 3.2), conditional (1.4 ± 0.5, 95% CI; 1.3, 1.8).

There was a significant relationship between jockeys who experience difficulty making weight and those who reported that they partake in physical activity outside of riding (p=0.001, [PHI] =0.370). Jockeys reported the use of exercise as a method to rapidly reduce body weight; 29.4% (n=25) utilised exercise alone, 32.9% (n=28) utilised a sweat suit while exercising, 4.7% (n=4) reported always using a sweat suit while exercising and 2.4% (n=2) did not use exercise for weight loss.

4.5.3 Current Physical Activity Habits

The jockeys were asked to report their current physical activity levels outside of riding related work. Sixty-six jockeys (77.6 %) reported they partake in other physical activity while 22.4% (n=19) of jockeys reported no physical activity outside of riding related work. There was no significant association between total flat (44.7%) and total NH licenses (55.3%) (p=0.067, [PHI] =0.198) or between licensed sub categories (p=0.052, [PHI] =0.302). The jockeys were asked to detail the physical activities they partake in using self-recall. Five common themes emerged: (1) cardio, (2) gym-based training, (3) golf, (4) boxing and (5) field-based games. The participation percentage and frequency of participation in physical activity per week in addition to a weekly sRPE (rated perceived exertion x time (minutes)) of these activities are represented in Table 4.2. There was a non-significant relationship between both weekly sRPE and age (r = -0.138; p=0.476), and weekly sRPE and jockey license (r = -0.279; p=0.142).

Table 4.2 Physical activity levels of active jockeys (n=66).

Activity	**Percentage Participation (%)**	**Frequency per week Mean ± SD** (95% CI)	**sRPE (AU) Mean ± SD** (95% CI)
1. Cardio	48.2 (n=32)	**3.4± 1.6** (2.9, 3.9)	**272.9 ± 134.8** (238.7, 321.2)
2. Gym based Training	10.6 (n=7)	**2.1 ± 1.2** (1.3, 2.9)	**315.4 ±115.1** (240.2, 390.6)
3. Golf	1.2 (n=1)	**1 ± 0** (1.0, 1.0)	**860 ± 28.2** (804.7, 915.3)
4. Boxing	2.4 (n=2)	**3 ± 0** (3.0, 3.0)	**630 ± 127.3** (453.6, 806.4)
5. Field based games	14.2 (n=9)	**1.3 ± 0.6** (0.9, 1.7)	**431.6 ± 76.4** (388.3, 474.8)

*sRPE = Session rated perceived exertion (session intensity x session duration in minutes).

4.5.4 Practice and Perceptions of Strength and Conditioning

4.5.4.1 Warm-up.

Forty-six jockeys (54.1%) reported that they performed a warm-up routine before racing. Of those jockeys, there was no significant difference between total flat and total NH jockeys (p=0.530, [PHI] =0.068) or between licensed sub-categories (p=0.129, [PHI] =0.258). Participating jockeys reported they most commonly completed static stretching (42.4%), light aerobic activity (16.5%), dynamic stretching (8.2%), muscular activation exercises (7.1%), foam rolling (4.7%) and other (2.4%).

The most frequent time reported for warm-up duration was 1-5 minutes (24.7%) with 8.7% of jockeys warming up for 20 minutes or greater.

4.5.4.2 Strength and conditioning (S&C)

Forty-two percent of Jockeys that participated in S&C (n=36) reported their most frequent type of S&C practice was; cardio (52.8%), high intensity interval training (33.3%), flexibility & mobility training (8.3%), resistance training (5.6%). Of those that did not participate in S&C, reasons for this included: “I don’t have time” (42%), “I am too tired following riding work” (14%), “I am fit enough from riding work” (14%), “I don’t enjoy it” (8%), “I don’t want to gain weight” (8%), “I am not aware of S&C classes close to my work place” (6%), “I don’t want to change current habits” (4%), “I don’t have access to specialist S&C information” (4%). There was no significant association in S&C participation between total flat and total NH licenses (p=0.085, [PHI] =0.187) or between license sub categories (p=0.237, [PHI] =0.190). Table 4.3 represents the type of S&C class that would most appeal to jockeys in addition to the reason for that selection. Boxing classes were the most popular type of S&C class requested by jockeys with an improvement in riding fitness the most common justification for this class type.

Table 4.3 Jockeys preferences for future S&C class types (n=85).

S&C Class type.	**Resistance training classes**	**Cardio based classes**	**Boxing Classes**	**HIIT**	**Flexibility Training**	**Injury Prevention Classes**	**Other**	**Total**	**Percentage %**
Rationale for choice.									
I enjoy it	0	3	2	1	0	0	0	6	7.0
It would be fun	1	1	10	0	0	0	1	13	15.3
Increase core strength	2	1	1	0	0	0	0	4	4.7
Improve riding fitness	0	7	11	8	0	0	0	26	30.6
Helps weight management	0	6	2	2	0	0	0	10	11.8
Increase overall strength	5	0	0	1	0	0	0	6	7.0
To prolong riding career	0	0	0	0	0	1	0	1	1.2
To improve riding performance	2	1	0	1	7	1	0	12	14.1
Prevent injuries	0	0	0	0	0	5	0	5	5.9
Improves overall well being	1	1	0	0	0	0	0	2	2.4
Total	11	20	26	13	7	7	1	85	
Percentage (%)	12.9	23.6	30.6	15.3	8.2	8.2	1.2		100%

*HIIT = high intensity interval training

4.5.4.3 Jockeys perceptions of S&C and sources of S&C information

The sources jockeys used to obtain S&C information were described by the respondents and found to be varied and included; the Irish jockey pathway (15.3%), other jockeys (15.3%), S&C coach (14.1%), internet (9.4%), and other (5.7%), while 40% reported that they do not source information on S&C or physical preparation strategies. Seventy-six percent of the jockey population reported that they would like more information on S&C and physical preparation strategies. Jockeys preferred method to receive this information was; email (25.9%), a jockey specific training app (24.7%), S&C classes (11.8%), online videos (5.9%), one to one consultation with an S&C coach (4.7%), social media (2.4%), fact sheet (1.2%). Jockeys perceptions of the benefits of S&C can be seen in Table 4.4. Although a high percentage of jockeys reported knowledge surrounding the benefits of S&C for various parameters, uncertainty among the population existed around the benefit of S&C on weight management and the effect of S&C on the speed of movement.

Table 4.4 S&C perceptions among jockeys (n=85).

Statement	I agree (%)	I neither agree or disagree (%)	I disagree (%)
S&C can improve your riding performance	88.2	10.6	1.2
S&C can reduce the risk of injury	84.7	0	15.3
S&C can slow your movement down	9.4	29.4	61.2
S&C can help you manage your riding weight	77.6	12.9	9.4
S&C can negatively affect your riding weight	8.2	38.8	52.9
S&C can improve your bone health	70.6	27.1	2.4
S&C can improve your balance and coordination	88.2	0	11.8
S&C can improve your general and specific endurance	94.1	2.4	3.5
S&C can improve your general and specific strength	91.8	4.7	3.5

4.6 Discussion

This is the first study to investigate the physical preparation strategies of jockeys. The findings of this study highlight that S&C practices are highly variable and inconsistent. Both the sample size and 100% response rate (n=85) was higher than other S&C related studies; Rugby 83% (Jones et al., 2016), major league baseball 70% (Ebben et al., 2005), rowing 54% (Gee et al., 2011), American football 86% (Ebben & Blackard, 2001). The higher response rate may highlight the elite athletes', in this case professional jockeys, receptiveness to sharing training habits and knowledge or the potential benefit of face-to-face interaction when collecting data over electronic methods as used in the aforementioned studies.

The results of this study reveal that the license category of a jockey is directly related to the number of race wins. The license type is also related to the amount of opportunities that jockeys receive with flat jockeys receiving more races on average per week than any other jockey license category (16.3 ± 8.7). These racing demands in addition to jockey working hours must be considered when writing physical preparation programmes. Data collection took part at the beginning of the flat season and end of the NH racing season which may have influenced the number of races available to jockeys. Additional hours of work is not usual practice for professional athletes where a large emphasis is placed on balancing the stressors of the sport with appropriate recovery to maximise performance in addition to minimizing injury risk (Kellmann, 2010). Jockeys work a large amount of weekly hours (34 ± 14) in addition to completing weekly races (7 ± 6). It is not surprising that fatigue is prevalent among the jockey population (Dolan et al, 2011) considering total riding commitments and ubiquitous difficultly with weight management reported by 55.3% of jockeys.

Jockeys are unique in comparison to other weight restricted sports in that they make weight daily (Wilson et al., 2015). Boxers habitually lose weight by restricting fluid and food intake in the week leading to competition (Hall & Lane, 2001) and this was also more common than exercise for rapid weight loss with jockeys (Dolan et al., 2013; Wilson et al., 2015). Sixty-seven percent of jockeys reported that they must rapidly lose weight at least once a month. Exercise alone is used by only 29.4% of jockeys to achieve their required weight which is lower than previous research reported at 48% (Dolan et al., 2013). Jockeys also employ poor dietary habits with the consumption of convenience food quite common (Dolan et al., 2011). In conjunction with low participation rates in additional physical preparation strategies outside of riding, it is not surprising that NH jockeys exhibit higher body fat percentages (13.84 ± 6.02) than other weight restricted sports such as boxing (9.76 ± 4.14) (Dolan et al., 2012b).

Approximately a quarter of jockeys (22.4%) reported no physical activity outside of riding related activity. Although 'riding out' is physically demanding (Kiely et al., 2019a) and jockeys work a large amount of hours, 'riding out' does not match the physiological demands of race riding and thus does not expose jockeys to the intensity of race riding. Of those that participate in physical activity outside of riding, cardio activity was the most popular and although this is used as a useful weight making tool, high intensity interval training (HIIT) may expose the jockey to exercise similar to the intensity of race riding. To quantify additional activity, acute arbitrary sRPE units were calculated. Although this is the first time exercise has been quantified in horse racing, sRPE has been validated as a measure of global internal training load (Rogalski et al., 2013). Cardio exhibited the lowest sRPE, and this may be due to the low intensity nature of the cardio activity. Acute load has been previously reported using arbitrary sRPE units in professional team games (Cross, Williams, Trewartha, Kemp, & Stokes, 2016; Malone, Roe, Doran, Gabbett, & Collins, 2017; Rogalski, Dawson, Heasman, & Gabbett, 2013), however normative data in weight restricted sports are absent. While these sports quantified physical training practice, only a limited number of jockeys partook in additional physical activity. Although gym-based training, golf, boxing and field based games were reported only boxing reached comparable levels with training in team sport (>1750 arbitrary units) (Rogalski et al., 2013). The low number of participants (n=2) that reported boxing activity in this study does not allow for translational comparisons. It is plausible that longer duration activities such as golf may have skewed the data with duration disproportionately impacting the relatively low intensity of the reported sessions.

Research has shown that an adequate warm-up can provide positive performance increments in both aerobic and anaerobic events with little evidence of detrimental effects (Fradkin, Zazryn, & Smoliga, 2010). The elite jockeys in this study reported that just over half the athlete population warm-up before racing (54.1%) with static stretching the most commonly utilised warm-up practice. Although further research is required on individual components of a warm-up, it is understood that static stretching may not be the optimal preparation strategy for events which require maximal exertion due to negative decrements in power (Shrier, 2004; Young & Behm, 2002).

S&C practices have been widely documented in elite athletes; however, no previous study has examined the physical preparation of jockeys in this regard. It is unsurprising that cardio is completed by over 50% of jockeys with its prominence as a weight making strategy also portrayed from the compiled data. Resistance training was the least commonly reported S&C modality utilised. This is in contrast with sports such as rowing, American football, Rugby union and swimming where resistance training is consistently practiced and the specifics of programming are also detailed (Crowley et al., 2018). Resistance training is known to have positive effects on performance in addition to health benefits through the maintenance and prevention of osteoporosis and sarcopenia (Winett & Carpinelli, 2001). With NH jockeys in particular exposed to regular falls (50.9/1000 rides) (Forero Rueda et al., 2010) in addition to the prevalence of osteopenia among the jockey population (Warrington, Dolan, & McGoldrick, 2009) resistance training must be advocated to all jockey licenses. Jockey's perceptions of the benefits of S&C and their most common sources of S&C information were reported. Of note is that 76% of jockeys reported interest in receiving further S&C information. Practitioners such as the Irish Jockey Pathway (a suite of professional performance services) and other related international organisations should consider that email, a jockey specific training application and S&C classes were the three most requested means to receive S&C related information.

4.7 Conclusion

This study provides a comprehensive insight into the physical preparation strategies typically used by professional jockeys. Jockeys work a high number of hours in addition to competing in multiple races per week. Only those jockeys participating in team sports in addition to riding reached a comparable training load to other professional athletes. A large percentage of jockeys believe S&C can improve riding performance, however participation rates in S&C are less than 50% with few performing resistance training. A greater understanding of jockey’s knowledge of physical performance and education services available to jockeys is warranted. It is also understood that jockeys do not partake in exercise which mimics the repeated high intensity demands of racing, however, there is a desire among jockeys to receive further support in the area. Outmoded cultural methods have been reported for making weight in horse racing (Warrington et al., 2009; Wilson et al., 2015) and this may also be true in physical preparation for many of the jockey athletes. A detailed analysis of the specific physiological demands of both flat and NH racing is required to inform both jockeys and coaches in terms of the implementation of optimal training practices. Future research is required to examine the effects of specific S&C interventions on riding performance and educational interventions on physical preparation habits.

4.8 Practical applications

The data and information presented in the study in relation to weight making strategies illustrate the need for educational and dietary interventions and specific individualised exercise programmes within this population. HIIT may be a useful training modality in bridging the gap between the physiological demands of ‘riding out’ and racing. Further educational information on the benefits and practice of S&C should be provided by professional support services in horse racing. S&C coaches can utilise the data reported in this study to inform current and future S&C practices in addition to how best to deliver S&C information to jockeys. Future questionnaires should look at the specific breakdown of S&C programmes for jockeys in relation to exercise type and prescribed load.

Chapter Five: Physiological Demands of Professional Flat and National Hunt Horse Racing

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5.1 Preface

Building on the findings presented in Chapter Four, the primary objective of this chapter was to investigate the relative physiological demands of flat and NH racing over short and long course distances. Findings from the review on physiological monitoring tools in Chapter Three informed the data collection methods utilised in this chapter. Evidence in Chapter Four indicated that many jockeys do not partake in S&C with only a small percentage of the population receiving exposure to high intensity training. This chapter monitored the intensities of various race distances for flat and jump jockeys. Three studies have previously investigated the physiological demands of racing with jockeys (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995) however, neither O' Reilly et al. (2017) or Trowbridge et al. (1995) referenced the demands relative to race distance. Cullen et al. (2015) investigated heart rate responses in flat racing from 1200 m to 1600m. While Cullen et al. (2015) summated that that both aerobic and anaerobic power were required in flat racing, no blood lactate concentration data was reported leading to ambiguity around the energy contribution of the anaerobic system in racing. It is thought that intensity and duration are important considerations for all training programmes impacting both the magnitude of the stress response and the time required for recovery (Seiler, Haugen & Kuffel, 2007). While limited data exists, a comprehensive understanding of the relative physiological demands would allow practitioners to establish sport specific training interventions. The demands relative to race duration and intensity were investigated over short and long races for flat and NH racing. The findings of this chapter, in addition to the conclusions drawn from Chapter Four, indicate that jockeys do not train to meet the high physiological demands of racing which has aerobic and anaerobic requirements.

5.2 Abstract

Limited information is currently available on the effect of race distance on the physiological demands of jockeys. This study aimed to quantify the respective demands of short and long flat and NH race distances. 20 professional jockeys (10 flat, 10 NH) participated in the study. The participants initially performed a graded incremental exercise test to volitional exhaustion on a treadmill to determine peak HR and blood lactate concentrations. Two competitive races (short and long) were then monitored on two separate occasions for each jockey type to obtain hydration, HR, blood lactate, and rating of perceived exertion data. Mean distances for the four races were; 1247.2 ± 184.7 m (short flat race), 2313.4 ± 142.2 m (long flat race), 3480.2 ± 355.3 m (short NH race), 4546.4 ± 194.3 m (long NH race). Mean HR for the long flat race was 151 ± 19 $b \cdot min^{-1}$ (79 ± 11% of HR_{peak}) which was significantly lower than all other race distances (p=0.000, ES=0.469). A longer NH race resulted in a significantly higher reported rate of perceived exertion (14 ± 2.8) than the short NH race (11.0 ± 1.5) (p=0.009, ES=0.271) while no significant difference was revealed between peak HR responses or blood lactate concentration when comparing other race distances ($P < 0.05$). The findings of the present study support previous limited research which suggests that horse racing is a high intensity sport, while rate of perceived exertion and mean HR fluctuate according to race distance. Future studies should look at developing a relevant physical testing protocol that would determine if a jockey is fit to meet the demands of racing.

5.3 Introduction

Horse racing is one of the oldest organised sports, yet there is a dearth of scientific research and application for jockeys. Horse racing is divided into two distinct categories; flat and NH racing. Traveling at velocities of up to 65km/hr, flat racing has no obstacles and takes place on a shorter course distance (1,000 m to 3,200 m). NH racing encompasses manoeuvring a thoroughbred racehorse weighing up to 500kg over obstacles with distances ranging from 3,200-7,200 m. Jockeys frequently ride over a range of course distances within their discipline. Flat racing jockeys are required to weigh between 52.7 and 64 kg while NH jockeys must weigh in between 62 and 76 kg. These weights are inclusive of the horse saddle and full riding gear (Cullen et al., 2015; Dolan et al., 2011). While maintaining the stipulated chronic low body mass, a sufficient level of conditioning is required to ride several races per day, multiple days per week with no established off-season (Cullen et al., 2015).

Individual athletes in sports such as running, cycling and eventing commonly differentiate between events within the sport and the relative physiological demands that the athlete is exposed to (Duffield, Dawson, & Goodman, 2005; Roberts, Shearman, & Marlin, 2009; Rodríguez-Marroyo, García-López, Juneau, & Villa, 2009). Despite the popularity of horse racing, few studies have investigated the physiological demands of racing (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995), and no study has evaluated the demands placed on jockeys relative to the race distance in flat and NH racing. Physiological demands can represent internal values that measure biological status or exercise intensity with the parameters of HR, blood biomarkers and ratings of perceived exertion commonly examined (Kiely et al., 2019b). In order to optimise jockey performance, it is important that researchers endeavour to provide information to S&C coaches and support staff in relation to the specific demands of both flat and NH racing in addition to specific distance related measurements of intensity. Across sports, such information is deemed valuable to facilitate optimal training load and competition preparation (Gabbett, 2010). Furthermore, it may be argued that for jockeys of equal skill, their fitness level ought to enhance performance as is evident in a multitude of other sporting codes (Bangsbo et al., 2006; Hitchens et al., 2011a; Sleivert & Rowlands, 1996).

Jockeys will typically maintain a position of forward propulsion, racing with the centre of mass acting through the jockey's foot while balanced on a thin strip of metal known as the stirrup (Figure 5.1). An increase in effort with higher intensity maximal pushing activity is then required in the final stages of a race (Wilson et al., 2013). From an initial quasi-isometric squat position, jockeys will lower their centre of gravity adopting a position of increased flexion at the knee and hip. At this stage jockeys aim to minimise movement of the lower body, squeezing the horse firmly with the inside of the lower leg, to encourage increased forward momentum. To lengthen the horses stride jockeys will then use their shoulders and arms to push out the horse vigorously at the neck with up to 2.5 pushes per second (Wilson et al., 2013). Maintaining balance and rhythm throughout each action in alignment with the horse's movement is imperative.

Figure 5.1 Riding position of jockey in the initial stages of a race.

Time and distance ranges have been reported in the literature for NH and flat racing respectively (Cullen et al., 2015; Trowbridge et al., 1995), however mean time for specific race distances has not previously been described in either race type, nor have they been compared. Only two studies have previously investigated the demands of flat racing with both studies denoting a high peak HR of 189 ± 5 $b{\cdot}min^{-1}$ (Cullen et al., 2015) and 186 ± 14 $b{\cdot}min^{-1}$ respectively (O'Reilly et al., 2017). Mean HR for flat racing has been previously reported at 180 ± 6 $b{\cdot}min^{-1}$ (Cullen et al., 2015) and 167 ± 12 $b{\cdot}min^{-1}$ (O'Reilly et al., 2017). As the latter study included 30 seconds 'pre- and post-race' in the analysis, it is probable that the mean HR was underestimated. Neither study provided information on blood lactate concentration responses, indicating the necessity of this research to compare events. Peak HR has been reported in NH racing as 184 $b{\cdot}min^{-1}$ with a mean range of 136 to 188 $b{\cdot}min^{-1}$, while peak lactate values were reported at 7.1 $mmol{\cdot}l^{-1}$, confirming the high physiological demands (Trowbridge et al., 1995).

While high physiological demands in racing have been previously reported, specific information on effective preparation strategies designed to enhance racing performance need to be improved. However, 'riding out', a daily work activity for jockeys, involves taking the horse through walking, trotting and cantering. The physiological demands of these gaits do not meet that of the demands the same athletes face in competition (Kiely et al., 2019a). Previous research has found that only 42% of jockeys participate in S&C practice (Kiely et al., 2020a) therefore, further sport specific training which includes relative competition demands is warranted among the jockey population. With great disparity between race distance and duration jockeys compete over, a greater understanding of relative physiological responses will assist in the development of specific race based conditioning programmes. The aim of the study was therefore to profile and compare the physiological demands of short and long race distances in flat and NH racing with respect to HR, blood lactate concentration, perceived exertion and hydration status.

5.4 Methods

5.4.1 Experimental approach to the problem

A testing protocol was devised to explore the physiological demands of professional jockeys. The research was broken into two stages consisting of an initial maximal treadmill test to obtain peak physiological data and the subsequent physiological monitoring of jockeys during competitive professional racing. The research was framed with a research question rather than a prominent hypothesis. Prior approval for the study was granted by the Irish Horse Racing Regulatory Board, the regulatory authority for Irish horse racing. The study was approved by the Waterford Institute of Technology research ethics committee in the spirit of the Helsinki Declaration.

5.4.2 Participants

20 professionally licenced jockeys participated in the study. The participants comprised of 10 flat jockeys and 10 NH jockeys. Both flat and NH jockeys were tested at separate times during their respective in-season. Participation in the study was voluntary with all jockeys receiving information on the risks and benefits of participation before providing informed consent. Informed consent documents (see appendix D) were signed and gathered for all participants prior to testing commencement.

5.4.3 Procedures

5.4.3.1 Anthropometrics and physiological baseline testing

On a non-racing day, height was measured to the nearest centimetre (cm) using a stadiometer (Seca, Leicester Height Measure). Body mass (kg) was recorded in minimal clothing using a portable digital scales (Salter, Germany). Participants were then asked to remain in a seated position for five minutes to obtain resting blood lactate (Lactate Pro, Akray, Kyoto-shi Kyoto-fu, Japan) from the earlobe and HR values (Polar H10 Electro, Kempele Finland). Participants completed a treadmill test to volitional exhaustion to determine peak HR and blood lactate concentration values.

The incremental running test to volitional exhaustion was completed on a motorised treadmill (Taurus, Germany) with an incline of 1 degree. Following a five-minute warm-up on the treadmill at 8 $km{\cdot}hr^{-1}$, a ramp protocol was employed with an initial velocity increase of 1 $km{\cdot}hr^{-1}$ each minute. A rate of perceived exertion (RPE) score (6-20) was collected at each speed and gradient change (Borg, 1982). When the participant reported an RPE of 14 arbitrary units, velocity was maintained and the gradient was thereafter increased by 1 degree each minute. The test was ceased once volitional exhaustion was achieved.

Maximal tests necessitate participants to exercise to the point of volitional exhaustion (Pescatello et al., 2014). The test was considered a maximal test if three of the following ACSM criteria were met: (1) A final HR of within 5 beats of the age-predicted maximum (220 $b{\cdot}min^{-1}$ – age); (2) A RPE of 19 or greater to establish volitional exhaustion; and (3) A final blood lactate value of 8 $mmol{\cdot}l^{-1}$ or more. These criteria were met with each subject. Peak HR was noted at the completion of the test from the 'Polar Beat' application. Blood lactate concentration was measured at minutes 1,3,5,7 and 9 post tests. When a decline in lactate was noted the previous score was taken as the peak concentration value.

5.4.3.2 Race data collection

Race data for flat and NH jockeys were collected within 4 weeks of the laboratory tests at various racecourses over short and long course distances on a turf track. Mean distances for the four races were; 1247.2 ± 184.7 m (short flat race), 2313.4 ± 142.2 m (long flat race), 3480.2 ± 355.3 m (short NH race), 4546.4 ± 194.3 m (long NH race). Air temperature and humidity were reported at the start of each race from the national weather forecasting application (Met Eireann, Dublin, Ireland). Following the completion of a pre-test medical screening form, USG was measured using a RS pro refractometer (RS PRO, Dublin, Ireland). USG values of <1.020 were considered indicative of euhydration, and values ≥1.020 indicative of hypohydration (Oppliger & Bartok, 2002).

A minimum of 60 minutes of no riding was required prior to each race to ensure blood lactate concentrations were at resting levels (≤ 2 $mmol \cdot l^{-1}$). Pre-race blood lactate concentration was taken within 15 minutes before the race start. The Polar H10 monitor was also fitted at this time to gather in race HR data. If blood lactate concentration levels were above resting values, the race was not monitored for the jockey and jockeys were tested on another racing day where they met the criteria.

Following the race, the jockeys finishing position was recorded. The raw HR data were automatically downloaded to the polar beat application (Polar H10 Electro, Kempele Finland). It was later time stamped and synchronised with the race start time to retrieve mean and peak HR values. Blood lactate concentration and RPE values were recorded between 5 and 7 minutes' post-race on return of the jockey to the weighing room.

5.4.4 Statistical analysis

Data were analysed using SPSS (Statistical Package for the Social Sciences V22.0, SPSS Inc, Chicago, Illinois, USA). Data were assessed for normality using a Shapiro-Wilk test while descriptive data were presented as mean and standard deviation (mean ± SD) with a 95% confidence interval (95% CI). To investigate if any differences existed between group means for the four race types (short flat race, long flat race, short NH race and long NH race), a one-way analysis of variance (ANOVA) was administered. A Tukey HSD post-hoc comparison was applied to determine the location of the differences between the four groups. Statistical significance was set at $p < 0.05$ level. Effect sizes (ES) for between group differences were calculated using Eta Squared with 0.2 considered a 'small' ES, 0.5 a 'medium' ES and 0.8 a 'large' ES (Cohen, 1988).

5.5 Results

5.5.1 Anthropometrics

Mean anthropometric data for both flat and NH jockeys are reported in Table 5.1. Mean values for peak HR and peak lactate concentration are also reported for both jockey groups from the volitional exhaustion test.

Table 5. 1 Anthropometrics, peak HR and peak blood lactate concentrations (n=20).

Variables	Flat Racing (n=10) Mean ± SD	NH Racing (n=10) Mean ± SD
Age (y)	26 ± 6.0	25 ± 4.0
Height (cm)	168.0 ± 5.0	174.0 ± 5.0
Weight (kg)	57.6 ± 2.4	65.0 ± 3.3
Peak HR ($b \cdot min^{-1}$)	192.0 ± 8.0	194.0 ± 9.0
Peak blood lactate concentration ($mmol \cdot l^{-1}$)	10.0 ± 2.5	11.1 ± 2.7

5.5.2 Climatic conditions and hydration levels

The mean temperature (°C), humidity (%) and USG ($g \cdot mL^{-1}$) for each race type are reported in Table 5.2. There was no significant difference between temperature or humidity when comparing the short and long flat races or the short and long NH races. However, the temperature and humidity were significantly higher during both flat races in comparison to the NH data collection period (p=0.000, ES=0.735).

Table 5.2 Internal and external variables for each race (n=20).

Variables	Flat Racing (n=10) Mean ± SD		NH Racing(n=10) Mean ± SD	
	Short Race	Long Race	Short Race	Long Race
Temperature (°C)	18.9 ± 1.4 $^{\dagger¥}$	17.6 ± 1.8 $^{\dagger¥}$	9.8 ± 3.5$^{\ddagger\Delta}$	10.3 ± 3.0$^{\ddagger\Delta}$
Humidity (%)	63.4 ± 7.4 $^{\dagger¥}$	60.7 ± 7.7 $^{\dagger¥}$	77.0 ± 5.1$^{\ddagger\Delta}$	77.2 ± 5.6$^{\ddagger\Delta}$
USG (g·mL$^{-1)}$)	1.018 ± 0.010	1.018 ± 0.010	1.023 ± 0.005	1.020 ± 0.008

$^{\dagger}p < 0.05$ significantly different from the short NH race group. $^{¥}p < 0.05$ significantly different from the long NH race group. $^{\ddagger}p < 0.05$ significantly different from the short flat race group. $^{\Delta}p < 0.05$ significantly different from the long flat race group.

5.5.3 Race characteristics and physiological responses

The race characteristics and physiological responses can be seen in Table 5.3. In NH racing, a longer race distance resulted in a significantly higher reported RPE than the short race (p=0.009, ES=0.271) while no significant difference was revealed between peak HR responses or blood lactate concentration when comparing other race distances. Mean HR in the long flat race (151 ± 19 b·min^{-1}) was significantly lower than the mean HR reported in all other race distances (p=0.000, ES=0.469). No significant difference was noted between the flat race distances when comparing other race distances for peak HR, RPE or blood lactate concentrations ($P < 0.05$).

Table 5. 3 Race characteristics and physiological responses of jockeys (n=20).

Variables	Flat Racing (n=10) Mean ± SD		NH Racing(n=10) Mean ± SD	
	Short Race	**Long Race**	**Short Race**	**Long Race**
Distance (m)	1247.2 ± 184.7	2313.4 ± 142.2	3480.2 ± 355.3	4546.4 ± 194.3
Time (s)	78 ± 12.2.0	157 ± 10.4.0	263 ± 33.0	355 ± 18.0
Finishing position	4 ± 2.0	5 ± 2.0	5 ± 3.0	5 ± 3.0
Mean HR ($b{\cdot}min^{-1}$)	172.0 ± 15.0 $^{\Delta}$ (89 ± 6% of Lab HR_{peak})	151.0 ± 19.0* (79 ± 11% of Lab HR_{peak})	181.0± 8.0 $^{\Delta}$ (93 ± 3% of Lab HR_{peak})	182.0 ± 9.0 $^{\Delta}$ (94 ± 3% of Lab HR_{peak})
Peak HR ($b{\cdot}min^{-1}$)	190.0± 12.0 (99 ± 4 % of Lab HR_{peak})	186.0± 14.0 (97± 4% of Lab HR_{peak})	192.0± 6 (99 ± 3% of Lab HR_{peak})	195.0± 9.0 (101 ± 3% of Lab HR_{peak})
RPE	13.0 ± 2.1	14.0 ± 1.3	11.0± 1.5 $^{¥}$	14.0 ± 2.8 ^{ᵻ}
Peak blood lactate concentration ($mmol{\cdot}l^{-1}$)	8.6 ± 2.5 (86 ± 14 % of Lab $[La]_{peak}$)	8.2 ± 1.5 (82 ± 16% of Lab $[La]_{peak}$)	7.4 ± 2.2 (50 ± 2% of Lab $[La]_{peak}$)	9.6 ± 3.2 (92 ± 40% of Lab $[La]_{peak}$)

*Significantly different from all sub groups. $^{ᵻ}p < 0.05$ significantly different from the short NH race group. $^{¥}p < 0.05$ significantly different from the long NH race group. $^{\Delta}p < 0.05$ significantly different from the long flat race group.

5.6 Discussion

While only three studies have investigated the physiological demands of horse racing previously, this study is the first to evaluate the demands of short and long race distances for either flat or NH racing. In that case, this current study has revealed differences in both HR and RPE between various race distances. It is envisaged, given the dearth of research, that these quantitative data sets will aid S&C coaches and sports medical staff in both the conditioning and rehabilitation of jockeys to meet racing demands.

In alignment with previous research (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995), peak HR measurements reported in this study indicate that a jockey has regular exposure to high intensity activity while racing. Mean and peak HR compare closely to the physiological strain experienced by both individual and team sport athletes. In competition, elite downhill mountain bike cyclists have exhibited mean and peak HR of 183 ± 6 b·min^{-1} and 194 ± 8 b·min^{-1} (Sperlich et al., 2012). In team sport, peak HR in both Gaelic football (201 ± 16 b·min^{-1}) and soccer (193 ± 3.3 b·min^{-1}) report similar peak HR values as experienced by jockeys (Reilly, Akubat, Lyons, & Collins, 2015; Santos et al., 2014) albeit for longer game durations. The recording of mean and peak HR provides a useful index of overall physiological strain during competitive races with the polar H10 monitor providing a gold standard device for assessments during intense activities (Gilgen-Ammann, Schweizer, & Wyss, 2019).

The peak blood lactate concentration reported across 3 race types (long NH race, short flat race and long flat race) appeared maximal in nature (≥8 mmol·l^{-1}) while the mean values of all races were higher than previously reported racing values (Trowbridge et al., 1995). With higher blood lactate concentrations reporting after racing when compared with pre-racing resting values (≤ 2 mmol·l^{-1}), it may be assumed that energy is mainly derived from anaerobic lactic and aerobic pathways

(Sperlich et al., 2012). Blood lactate concentration is frequently used as an indicator of energy production from anaerobic glycolytic processes. Although no blood lactate accumulation data are available from jockeys 'riding out' practitioners should ensure jockeys experience anaerobic activity to enhance lactate clearance (Gastin, 2001) and aid recovery between races.

NH jockeys reported a significantly higher RPE in the long race (14.0 ± 2.8) when compared to the short NH race, however there was no significant difference for HR or blood lactate concentration between the short and long NH races. The increased RPE may be linked to the longer duration of the event (355 ± 18 s). It is understood that RPE is a proven methodological approach to monitoring training intensity with an ICC of 0.88 when investigating high, moderate and low intensity sessions (Day et al., 2004; Herman et al., 2006). With jockeys reporting higher exertion levels over longer distance races, RPE may provide a valuable metric to replicate racing intensity with gym based exercises.

While no significant difference was noted in hydration status between the four races, flat jockeys reported to be in a state of hypohydration (USG ≥1.020). While no association was evident with HR or RPE in this study, body mass loss through dehydration can elevate HR and perceived exertion among athletes (Murray, 2007). There was a significant difference between temperature and humidity values when comparing the flat and NH racing seasons. The varied weather conditions are aligned with expected seasonal differences between the respective flat and NH racing seasons. While significantly higher humidity and temperature occurred during the flat data collection period, mean HR was lower for both flat race distances. An increase in air temperature is frequently associated with homeostatic disturbances. Adequate hydration strategies during competition is essential to minimise changes to homeostasis (Sleivert & Rowlands, 1996).

There are several limitations to the current study. The sample size was small so climatic conditions, ground conditions, the use of different horses and the fitness of the participants may have influenced the findings. Although hydration levels were reported with no significant difference between races, energy intake was not accounted for with each jockey. In addition, the HR reported may be elevated beyond the normal HR-$\dot{V}O_2$ relationship due to prolonged isometric contractions during riding, climatic conditions or emotional stress. Governing authorities in horse racing do not permit the measurement of $\dot{V}O_2$ during competition so alternative metrics as used in this study should be utilised to attain physiological feedback. In addition to relative HR and blood lactate values reported in this study, future studies should provide a relative level of fitness for each jockey group to investigate if there is an association between jockey fitness and the physiological responses during racing.

5.7 Conclusion

This was the first study to profile the physiological demands of flat and NH racing over two distances. There are significant differences in humidity and temperature for the flat and NH racing seasons in line with expected seasonal differences. Little variation however, was observed in hydration status or blood lactate concentration between jockey licence types. RPE reports produced a novel finding with jockeys perceiving longer races to require greater levels of exertion. In summary, this research specifies that both flat and NH jockeys experience significant physiological demands during racing with near maximal HR and blood lactate concentrations identified across all race types. Energy contributions appear to be from both the aerobic and anaerobic energy systems as previously suggested in the literature. These high demands in addition to the relevant health risks associated with making weight suggest horse racing is far more demanding than is currently recognised. Future research should look at developing a relevant physical testing protocol that would determine if a jockey is fit to meet the demands of racing.

5.8 Practical applications

As jockeys do not experience high physiological strain while 'riding out,' they should be encouraged to perform periods of high intensity efforts that mimic and exceed the HR demand and blood lactate concentration experienced in racing. These high intensity efforts while similar to all jockey licence types should focus on the body positions and movements that will be used in the subsequent performance. With both aerobic and anaerobic pathways systematically contributing to energy production in racing, HIIT training can be used to improve fitness and enhance both energy systems (Foster et al., 2015). Particular attention should be given to prolonged isometric squatting positions with flexion of the hip and knee and culminating short high intensity pushing activities. While similar intensities can be prescribed by S&C coaches to flat and NH jockeys and jockeys can ride over multiple race distances during a race meeting, exercise duration can be tailored to specific race distances. With jockeys reporting higher RPE values in longer distance races, jockeys should be exposed to relevant duration and intensities for these distances. The current findings provide a reference point for coaches to address the physiological development of the jockey with relative race duration and intensity ranges provided for flat and NH racing.

Chapter Six: Test-Retest Reliability of the Jockey-Fit Testing Battery

Kiely, M., Warrington, G., McGoldrick, A., Pugh, J., Hague, D., Middleton, W and Cullen, S. (2020). Design and test-retest reliability of the Jockey-Fit Testing Battery.

6.1 Preface

The previous chapter detailed the physiological demands of racing for flat and NH jockeys. The findings align with previous research in horse racing (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995) displaying high intensity and near maximal physiological responses in both flat and NH racing. The high intensity nature of horse racing accompanied by poor physical preparation strategies employed by the jockeys, as outlined in Chapter Four, indicate that the jockeys may not be prepared to meet the demands of their sport. The demands of professional racing convey that jockeys must have high fitness levels however no scientifically robust testing battery is available to practitioners to test jockey fitness. Chapter six proposes and investigates the test retest reliability of a fitness testing battery for the industry. As outlined in the previous chapters, specific training interventions are required for the jockey population. However, there is currently no reliable fitness testing battery for jockeys in horse racing. A fitness testing battery can assess jockey fitness, the success of relative fitness interventions in addition to providing a physical profile of professional jockeys both nationally and internationally. The focus of the current chapter was to choose valid and sport specific fitness tests to form a testing battery for the horse racing industry and investigate the test-retest reliability of the battery with jockeys. This chapter concludes the empirical research within the thesis. Conclusions and practical applications will then be drawn in Chapter Seven from the relative findings in this and former thesis chapters.

6.2 Abstract

The purpose of the study was to test the reliability of a sport specific physical testing battery for professional jockeys. Tests were included in the study based upon; (1) an extensive review and appraisal of the existing literature on the reliability of the test, (2) assessment of the logical validity of the test to measure a variable relative to the specific demands of the sport and (3) feasibility of the test to be readily implemented within the horse racing industry. Tests of flexibility (sit and reach), isometric strength (IMTB), strength endurance (revised push up test), torso stability (McGill torso endurance tests) and aerobic power (3-minute Wattbike test) were chosen as the fitness parameters to test. To establish the reliability of the fitness testing battery, 20 trainee jockeys performed 6 physical tests on two occasions, 7 days apart. Of the 6 tests, the sit and reach test, isometric mid-thigh pull (IMTP), torso side bridge tests, revised push up test and Wattbike 3-minute test ($\dot{V}O_{2max}$ & mean minute power) achieved the minimum acceptable reliability (ICC>0.7). All tests, with exception to the torso extensor test (ICC=0.50), demonstrated good to excellent relative reliability (ICC 0.83-0.98). The IMTP, despite displaying good reliability (ICC=0.83 (0.57-0.93)) displayed a significant difference between each individual's score from test one to test two (t19=-2.964, p=0.008, ES=0.36). The Jockey-Fit Testing Battery was found to reliably rank participants across the identified physical fitness parameters while also displaying an appropriate level of sensitivity to detect small changes in athlete performance for flexibility, muscular endurance, torso stability, MMP and estimated $\dot{V}O_{2max}$. Future research should investigate criterion validity of the tests within the Jockey-Fit Testing Battery.

6.3 Introduction

Physical fitness testing batteries are utilised widely by sports science practitioners, coaches and academics to assess athletes due to increased awareness of the importance of adopting a scientific approach to physical preparation. Physical fitness tests that take place outside laboratory conditions offer sports scientists, athletes and coaches sport specific modalities to assess relevant fitness components of the sport (Boddington et al., 2001), yet there is no evidence of valid and reliable fitness tests for evaluating fitness with jockeys.

Horse racing is unique to other sports in that male and female jockeys compete against each other in multiple races per day, several days per week, with no specified off-season (Dolan et al., 2011; Kiely et al., 2020a; Leydon & Wall, 2002). It is proposed that professional jockeys must have a strong metabolic drive to meet the high physiological demands of racing (Trowbridge et al., 1995). High peak HR values have been observed in flat racing by Cullen et al. (2015) (189 $b{\cdot}min^{-1}$) and O'Reilly et al. (2017) (186 $b{\cdot}min^{-1}$) and NH racing (162-198 $b{\cdot}min^{-1}$) (Trowbridge et al., 1995) racing. Original research in NH racing reported post-race blood lactate values ranging from 3.5 to 15 $mmol{\cdot}L^{-1}$ indicating that a high metabolic intensity is required in racing (Trowbridge et al., 1995). Recent evidence by Kiely et al. (2020) affirms a high metabolic demand in both flat and jump racing with contributions from both the aerobic and anaerobic energy pathways.

Current evidence suggests 'riding out' does not replicate the high physical demands of competitive racing with both HR and cardiorespiratory demand of 'riding out' reported to be lower (Kiely et al, 2019a). Additionally, less than half of the Irish jockey population participate in S&C or adopt physical preparation strategies which meet the intensity experienced in racing (Kiely et al., 2020b). The lack of a valid and reliable physical testing battery for jockeys has hindered specific research into jockey performance. A physical fitness testing battery would allow the evaluation of sport specific training interventions (Cullen et al., 2015), the ranking of jockey athletes in addition to facilitating the collection of normative data for jockeys on a national and international level.

For a performance testing battery to be valid, it must measure sport specific performance parameters (Currell & Jeukendrup, 2008). Although sporting performance can be argued to be a construct (Currell & Jeukendrup, 2008), logical validity should be applied in the selections of tests to form the testing battery (Thomas & Nelson, 1990). In terms of specific racing technique, jockeys typically maintain an isometric position with the centre of mass acting through the ball of the foot (figure 6.1a). In this position of forward momentum, the hands hold the reigns to control the speed of the horse. This action can take the form of a sustained quasi-isometric hold or pull if the horse is keen to run forward. In the final furlongs of a race an increase in intensity is required with greater physical efforts (Cullen et al., 2015; O'Reilly et al., 2017; Trowbridge et al., 1995; Wilson et al., 2013). Jockeys lower their centre of gravity adopting a position of increased flexion at the knee and hip (figure 6.1b). Known as the 'drive position', jockeys aim to restrict the movement of the lower body, squeezing the horse firmly with the inside of the lower leg, to encourage increased forward momentum. In an attempt to lengthen the horses stride, jockeys will then use their shoulders and arms to push out the horse vigorously at the neck with up to 2.5 pushes per second (Wilson et al., 2013). While simulator based fitness tests (Cullen et al., 2015; Wilson et al., 2013) and tests of flexibility and isometric strength (Hitchens et al., 2011a) have previously been tested with jockeys, no reliability research with a jockey cohort has been performed.

Figure 6.1a The quasi-isometric position in the initial stages of a race. Figure 6.1b Jockeys in the "drive position" in the final stages of a race while pushing out the horse.

Prior to the interpretation of results from a testing battery, it is pertinent that the individual tests are reliable (Lubans et al., 2011). Intra-class correlation (ICC) is the most commonly cited reliability test but it has been encouraged that it should not be the only statistic employed (Atkinson & Nevill, 1998; Hopkins, 2000). Standard error of measurement can account for the variability of an individual's values on repeated testing occasions (Drinkwater, Pyne, & McKenna, 2008) while magnitude-based inferences can provide more meaningful interpretations of fitness tests results from a statistical perspective (Drinkwater et al., 2008). While coaches may have developed their own fitness tests, no scientifically designed or tested fitness testing battery exists for professional jockeys despite horse racing's long history as a sport. In addition to providing a database for jockey profiling the battery will provide a platform to assess physical training interventions with the jockey population. The aim of this study was twofold: (1) form a testing battery that was logically and scientifically valid for the horse racing industry and, (2) to investigate the test-retest reliability of the physical testing battery with trainee jockeys.

6.4 Methods

6.4.1 Participants

Participants comprised of 20 (8 females and 12 males) trainee jockeys from the racing academy and centre of education (RACE). Age and anthropometrics (mean ± SD) for the participants were; age (17.3 ± 1.3 years), height (165.5 ± 6.2 cm) and body mass (56.1 ± 7.7 kg). Study approval was sought and obtained from Waterford Institute of Technology ethics committee in the spirit of the Helsinki Declaration. Participation in the study was voluntary with all participants receiving information on the risks and benefits of participation. Informed consent (see appendix E) was obtained from all participants while parental consent was received for those under 18 years of age.

6.4.2 Measures

Tests were chosen for inclusion in the reliability study based upon three criteria: (1) an existing body of literature on the reliability of the particular test, (2) logical validity of the test to measure a variable relative to the sport and, (3) feasibility and portability to implement the test as part of a larger battery within the horse racing industry. Following a review of the literature and observational analysis of the jockeys riding gait the subsequent components of fitness were assessed; flexibility, isometric pulling strength, upper body muscular endurance in the form of a push, torso stabilisation and aerobic fitness. All assessments were completed at RACE on two occasions, seven days apart (test one and test two). Identical protocols were followed on each testing day with test sequencing following ACSM guidelines (Harmann, 2008) to optimise energy systems and skill coordination (Miller, 2012). Flexibility, muscular strength, muscular endurance and aerobic fitness were assessed following a standardised RAMP warm-up protocol (Jeffreys, 2007)(see appendix F). Three minutes passive rest was implemented between tests (Pescatello et al., 2014). The protocol was completed in 70 minutes for each participant which was inclusive of a warm-up (12 minutes). Participants were asked to replicate their fluid and food intake on the day of testing while avoiding strenuous exercise for 48 hours before testing. No test-specific feedback was provided for either testing day, however general encouragement was offered by the tester in the form of “well done or “keep cycling” which was common to both trials. All testing was performed at the same time of day to minimise the effect of circadian rhythms. The testing room was set at 17 degrees on both days with humidity less than 60%.

6.4.2.1 Flexibility

Jockeys hinge forward at the hips while riding elongating the hamstring muscles. The sit and reach test is reliable and valid to measure the extensibility of the hamstring muscles (ICC=0.67) but not for measuring lumbar extensibility (Mayorga-Vega, Merino-Marban, & Viciana, 2014). Shoes were removed and participants were asked to sit with legs extended in front of the sit and reach box (Cartwright Fitness, United Kingdom). Feet were placed slightly apart with toes pointing up and the soles of the feet against the base of the step. Knees were instructed to be pushed against the ground. Each participant placed one hand on top of the other and reached slowly forward. The furthest point a participant could reach and hold for three seconds was recorded in centimetres (cm) with the mean of three trials recorded.

6.4.2.2 Isometric Strength

An isometric semi-squat position (Roberts et al., 2009) is performed by jockeys while also retaining an isometric pull to restrain the horse (Wilson et al., 2013). An isometric mid-thigh pull dynamometer (IMTP) (Takei, Japan) was used to assess isometric strength. Participants were asked to stand upright on the base of the dynamometer. A goniometer was used to ensure participants stood in a position of flexion at the hips (125 degrees) and knees (140 degrees) with arms straight. Several postures are reliable when investigating both within and between session reliability (Comfort, Jones, McMahon, & Newton, 2015) and although underestimating peak force, it is a valid field measure (ICC=0.91) to assess isometric strength (Till et al., 2017). Participants were asked to pull with maximum force for 3 seconds following a 3 second countdown (Beckham et al., 2013). Three trials were completed with three minutes’ rest between trials. Both test set up and reporting of mean force output (newton) were aligned with previous reliability research (Comfort et al., 2015).

6.4.2.3 Muscular Endurance

The revised push up test is a reliable test with interscorer objectivity and criterion validity (ICC=0.80) when compared to bench press performance (Baumgartner, Oh, Hyuk, & Hales, 2002) and was used as an upper body muscular endurance test with pushing frequency deemed an important racing attribute (Wilson et al., 2014b). Participants were asked to position themselves face down on the floor with the hands placed directly under the shoulder on the tape line with fingers pointed forward. From the starting position, participants lowered their body until all of the body from chest to thigh made contact with the floor. Elbows were kept along the sides of the body for both upward and downward motions with full extension of the elbow at the top position. Female participants followed the same protocol while positioned on the top of the knees. In alignment with other tests results repetitions were presented as a group mean. Participants continued until no more push-ups could be performed with the correct form. Resting by the participant or alterations to body position as set out by Baumgartner et al (2002) resulted in test termination.

6.4.2.4 Torso endurance side bridge test

Jockeys aim to minimise movement while racing (Walker et al., 2016a) and specific isometric training can induce immediate changes in core stiffness (Lee & McGill, 2017). The McGill side bridge test challenges the quadratus lumborum and abdominal wall to enhance spine stability (McGill, Juker & Kropf, 1996). It was performed to measure stiffness and torso stability previously demonstrating a reliability coefficient of 0.99 (McGill, Childs, & Liebenson, 1999). The starting position for the side bridge test required the participant to be on their side with both legs extended on the ground. The participant's lower arm was positioned under the body and the upper hand placed on the opposite shoulder keeping both legs extended and the side of the feet on the floor. The timer was started when hips were extended off the ground. The torso was supported only by the participant's feet, the elbow and forearm. When the hips dropped or touched the ground the test ended and time in seconds was reported. A three-minute rest period was implemented between testing the left and right sides respectively.

6.4.2.5 Torso endurance extensor test

The forward leaning position a jockey adopts while riding extends the muscles of the lower back. The McGill back extension test was performed to measure the endurance of the torso and lower back having previously exhibited a reliability coefficient of 0.97 (McGill et al., 1999). The participant was instructed to be prone with the iliac crest positioned over the table's edge. With arms supported initially, the participant's lower legs were anchored to the table by a tester. The aim of the test was to hold a horizontal, prone position for as long as possible. The timer was started when the participant placed their arms across the chest. Once the participant broke the horizontal body position, the test was terminated and time in seconds was reported.

6.4.2.6 WattBike 3-Minute Test

Aerobic power is a desired physical attribute to be a successful jockey (Cullen et al., 2015). A standardised three-minute peak aerobic test was performed on a Wattbike (WattBike, Nottingham) to determine estimated aerobic power ($\dot{V}O_{2peak}$) and mean minute power (mmp) per kilogram (kg). It has been previously reported that the 3-minute all out test was highly repeatable there was no significant difference (p=0.75) in $\dot{V}O_{2peak}$ when compared with a ramp protocol (Burnley, Doust, & Vanhatalo, 2006) and is a valid and reliable tool for performance assessments (Wainwright, Cooke, & O'Hara, 2017; Hanson et al., 2019). The participant's age and body mass were entered into the bikes computer prior to test commencement. The bike saddle was placed at the height of the bony protrusion of the hip for each participant. Air resistance was set at three while magnetic resistance was set at zero. The data screen was blocked from the participant's view on both testing days. Participants performed a three-minute warm-up at 80-90 RPM. The participants were then instructed that they were to "pedal as fast as possible for three minutes". On completion of the test, $\dot{V}O_{2peak}$ and Mean minute power (MMP) were recorded from the presented values on the Wattbike screen.

6.4.3 Statistical Analysis

Data were analysed using SPSS (Statistical Package for the Social Sciences V22.0, SPSS Inc, Chicago, Illinois, USA). Data were assessed for normality using a Shapiro-Wilk test while descriptive data were presented as mean and standard deviation (mean ± SD). An ICC with a 95% confidence interval (95%CI) was used to investigate relative agreement between test one and test two. Based on a 95% CI of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.9 were considered indicative of poor, moderate, good, and excellent reliability (Koo & Li, 2016). A minimum acceptable reliability level was determined with an ICC >0.7 (Baumgartner & Chung, 2001). A paired sample t-test ($p \leq 0.05$) was also administered to investigate if any difference existed between mean scores on test day one and test day two, enabling clarification of absolute reliability for tests with ES calculated using Cohens' *d*. Standard error of measurement (SEM) was computed to quantify the extent to which the results of a repeated measure with the same testing tool are distributed around the participants 'true score' (Ali et al., 2007). The formula used to calculate SEM values was: $SD_{pooled} * \sqrt{1} - ICC$.

6.5 Results

An initial literature review revealed that the physical parameters of flexibility (Westerling, 1983), strength (Hitchens et al., 2011a), stability (Sainas et al., 2016), strength endurance (Wilson, 2014b) and aerobic power (Cullen et al., 2015) were attributed to jockey performance. A further extensive investigation of the literature identified valid, reliable and portable methods to assess each parameter. The sit and reach test (flexibility), IMTP (strength), MgGill torso endurance tests (stability), revised push up test (strength endurance) and Wattbike 3-minute test (aerobic power) were included in the study design for reliability analysis with the jockey cohort. Descriptive statistics, ICC, p-value and SEM are presented in Table 6.1 for between session results. Good to excellent between-session reliability was observed for all tests with exception to the torso extensor test. The sit and reach test, IMTP, torso side bridge tests (left & right), revised push up test and Wattbike 3-minute test ($\dot{V}O_{2max}$ & MMP) achieved the minimum acceptable reliability criteria (ICC > 0.7). A significant but small difference was present between mean scores for IMTP for test one and test two ($p \leq 0.05$, ES = 0.36) however no significant difference ($p \leq 0.05$) was detected between other tests.

Table 6.1 Between session reliability of physical testing variables.

Variable	Testing day one Mean ±SD	Testing day two Mean ±SD	p-value	ES	ICC (95%CI)	SEM
Sit and Reach Test (cm)	31.66 ±6.99	31.86 ±6.60	0.66	0.03	0.98 (0.94-0.99)	0.91
Isometric Mid-thigh pull (N)	64.15 ±16.11	72.98 ±18.60	0.01*	0.36	0.83 (0.57-0.93)	7.13
Torso Extensor Test (s)	165.90 ±36.40	161.00 ±37.90	0.60	0.15	0.50 (0.25-0.80)	26.28
Torso left side bridge Test (s)	104.15 ±39.68	98.15 ±30.75	0.14	0.13	0.93 (0.83-0.97)	9.37
Torso right side bridge Test (s)	106.55 ±43.87	103.50 ±38.45	0.60	0.08	0.89 (0.73-0.96)	13.65
Revised Push Up Test (reps)	20.60 ±6.41	20.20 ±5.34	0.69	0.09	0.84 (0.60-0.94)	2.36
WattBike 3-Minute Test (MMP)	174.60 ±41.52	168.85 ±37.92	0.36	0.13	0.87 (0.66-0.95)	14.33
WattBike 3-Minute Test ($\dot{V}O_{2max}$)	45.87 ±10.19	43.83 ±10.82	0.95	0.60	0.93 (0.82-0.97)	2.78

Key: SD = Standard Deviation; ES = Effect size; ICC = Intraclass Correlation Coefficient; CI = Confidence Interval; SEM = Standard Error of Measurement; * significant difference in mean between test day one and test day two.

6.6 Discussion

The purpose of this study was to investigate the test-retest reliability of a physical testing battery for jockeys. The feasibility and practicality of field based tests for administrators is a primary concern, however practitioners also need to be assured that tests are reliable and valid to measure a relevant and specific fitness variable. Currently, no reliable fitness testing battery exists in horse racing and this has major implications for practitioners. Jockeys are not preparing to meet the high physiological demands of racing (Kiely et al., 2020b) and the development of a sport specific testing battery for jockeys would optimise the monitoring of physical fitness strategies to enhance jockey performance and also health and safety within the horse racing industry (Cullen et al., 2015).

The administration of tests by practitioners within the horse racing industry was a primary consideration during the design phase of the testing battery. The Jockey-Fit Testing Battery was formed based on physical fitness attributes identified in the literature for riding and racing. While jockeys attain a forward leaning, semi squat position, it is possible that lower limb isometric strength is associated with performance as is the case with sailing (Vangelakoudi et al., 2007). However, no field based test was identified in the literature that provided a reliable and portable measure of isometric endurance in a relevant riding position. All chosen tests were both portable and easily administered for practitioners in the horse racing industry. Gold standard methods exist but were not employed for the measurement of isometric strength and aerobic power. IMTP using force plates is reliable for the measurement of peak force, rate of force development and impulse (Dos'Santos et al., 2018; Keogh, Collins, Warrington, & Comyns, 2020). While there are now portable racks for the measurement of IMTP (Dos Santos et al., 2018; Keogh et al., 2020), force plates are an expensive measurement tool for large scale implementation within a sporting industry and require calibration for each use. Additionally, an incremental ramp protocol is generally considered a criterion method to evaluate aerobic power using blood lactate concentration and gas exchange criteria (Burnley et al., 2006). The lab based tests although demonstrating concurrent validity to a gold standard criterion would not be ecologically valid for implementation within the industry. It is plausible that a simulator based fitness test may provide a test of criterion validity for jockeys however reduced sympathetic tone and HR have been reported on horse riding simulators when compared to riding a horse (Cullen et al., 2015; Ille et al., 2015).

All tests with exception to the torso extensor test, demonstrated good to excellent relative reliability. The torso extensor test, while deemed a sport specific test, was not found to be scientifically robust from test one to test two and was therefore excluded from the Jockey-Fit Testing Battery. The p-values and confidence intervals presented suggest there can be significant within subject variation for individual tests despite relative agreement between group means. This is evident for the IMTP which displays good relative reliability (ICC = 0.83 (0.57-0.93)) but a significant difference between each individual's score from test one to test two ($t_{19} = -2.964$, $p=0.008$, ES = 0.36). With a small but significant increase observed from test one to test two for IMTP, prohibiting absolute agreement on the tests reliability, it is plausible that a learning effect has occurred (Hopkins, 2000). In this case practitioners should implement a familiarisation trial prior to testing to improve the precision of the IMTP test outcome. Researchers recommend the use of SEM and ICC to identify absolute reliability with low levels of standard error indicating high levels of score accuracy (Atkinson & Nevill, 1998; Weir, 2005). The seven-day test-retest period used in this study is aligned with other sport science reliability trials (Boddington et al., 2001; Comfort et al., 2015; Lubans et al., 2011).

Limitations of this study exist. While it is suggested a familiarisation session can improve the reliability for the IMTP (Dos'Santos et al., 2018), one did not occur in this study. It is envisaged that a jockey population who work an average of 34 hours a week in addition to racing multiple times per week (Kiely et al., 2020a) will not have availability for familiarisation trials. A larger sample size and the inclusion of an additional third trial would enhance the exactness of the reliability estimates (Lubans et al., 2011). A further limitation of the testing battery is that it does not measure a jockey's fitness in a relevant riding position. It is proposed that jockeys experience a quasi-isometric effect while riding but the seated position of the Wattbike test does not expose a jockey to aforementioned physiological stress. Furthermore, while aerobic capacity can be accurately estimated, the Wattbike test does not provide a measure of anaerobic capacity which is difficult to quantify using exercise tests (Gastin, 2001). Finally, the placement of the Jockey-Fit Testing Battery in a jockeys racing season is an important consideration for practitioners. Acute exposure to intense training or competition (Drinkwater et al., 2008) or rapid weight loss as occurs frequently (Dolan et al., 2013) can negatively affect testing performance.

6.7 Conclusion

When investigating test-retest reliability of the Jockey-Fit Testing Battery, absolute agreement was achieved for the sit and reach test, the torso side bridge tests (left and right), the revised push up test and the WattBike 3-minute test (MMP and estimated V02max). The aforementioned tests can therefore reliably detect change in athlete performance over two testing time points. Relative agreement was achieved for the IMTP. The IMTP has the ability to rank jockeys in the same position over two testing time points but a familiarisation session with jockey athletes is recommended before the inclusion of the IMTP as an increase in test scores was observed from test one to test two indicating a potential learning effect. While relatively reliable, minimising this learning effect may achieve absolute reliability. Tests included in the Jockey-Fit Testing Battery are both statistically and logically valid to test jockey specific fitness attributes. In conclusion, the Jockey-Fit Testing Battery is valid and can reliably rank order participants, across two testing time points while it also displays the sensitivity to detect small changes in individual athlete performance for flexibility, muscular endurance, torso stability, MMP and estimated $\dot{V}O_{2max}$. With little research in performance related metrics for jockeys in horse racing, future studies should investigate criterion validity of the tests within the Jockey-Fit Testing Battery and associations with key performance indicators in horse racing.

6.8 Practical applications

While the focus of S&C programming for jockeys should be on improving riding performance and not just specific fitness testing scores, the Jockey-Fit Testing Battery can be used to evaluate the effectiveness of implemented training strategies in the industry. Furthermore, it can facilitate the collection of normative data for professional jockeys across all racing nations and licence types for comparative purposes. Finally, the Jockey-Fit Testing battery can be applied by medical teams in horse racing to assess jockey fitness and compare results to baseline measures, before a jockey returns to racing following injury. Future research may investigate the development of a pioneering horse racing simulator which exposes jockeys to the relevant physiological demands of professional racing as recently updated by Kiely et al (2020b). This may provide a mechanism to design an ecologically valid test of aerobic and anaerobic fitness in addition to the proposed field tests.

Chapter Seven: General Discussion and Conclusi

7.1 Preface

The thesis aimed to investigate the race demands and preparation strategies of professional jockeys to inform the development of a physical testing battery for the horse racing industry. To address the primary aim, the thesis was divided into four distinct but interrelated sections; The review of literature (Chapter Two) provided a synthesis of jockey research spanning 27 years to initial work by Labadarios et al. (1993). The following chapter (Chapter Three) included a narrative review on the application of physiological monitoring tools in a competitive and individual sporting environments. The first empirical study (Chapter Four) surveyed the physical preparation strategies of jockeys. The second research study examined the physiological demands of flat and NH racing over short and long race distances (Chapter Five). Finally, the third empirical study (Chapter Six) investigated the test-retest reliability of the Jockey-Fit Testing Battery. The three empirical chapters provide a complex and multifaceted account of the lifestyle and demands of a professional jockey while providing scientific evidence and resources to enable practitioners in the industry to advance the performance and recovery strategies of jockeys. The findings of this thesis are unique. To the best of the author's knowledge study two and four (Chapters Four and Six) are the first studies in their respective areas while study three (Chapter Five) builds on previous research but provides specific and novel physiological data for race distance and type. Key findings, practical applications and future recommendations from the three empirical research chapters are now presented.

7.2 Key findings

Chapter Two to Chapter Six provided a multifaceted account of physiological monitoring tools and known physiological demands of racing in addition to physical preparation strategies and physical fitness testing for jockeys. The synthesis of available literature in Chapter Two presented an extensive summation of the athlete, physiological variables in racing and information which aided research design and analyses. Highlighted in the review was the potentially important but understudied relationship between physical preparation and the physiological demands of the sport.

Given the dearth of information on the performance monitoring of jockeys presented in Chapter Two, Chapter Three provided a focused review on physiological monitoring tools which could be applied in the field. There was a dearth of published research in relation to the application of physiological monitoring tools in competition with individual sport athletes. A number of monitoring tools including HR, biochemical monitoring and subjective responses were identified reliable and valid data for experimental purposes including exercise dose responses, exercise intensity and exercise performance. Practical application by the practitioner in the elite environment requires attention. The monitoring tool should be user friendly and time efficient while also ensuring it does not negatively affect the athlete's pre-performance routine. If the device is to be worn during completion, it should be comfortable for the athlete and be permitted to be worn by the regulatory authorities. The selection of monitoring devices for data collection in Chapter Five were informed by these findings.

Chapter Four investigated the physical preparation strategies of professional jockeys using a purpose designed questionnaire. The questionnaire explored physical preparation strategies under four headings: a) background information; b) making weight and currently associated exercise habits; c) current physical activity habits; and d) the practice and perceptions of S&C. The main findings of the study revealed that jockeys time is invariably limited, with long working hours (34 ± 14 hours) in addition to time spent racing each week. Over half of the surveyed population (55%)

were experiencing difficulty making weight, a finding that is commonly reported in the previous literature (Waldron-Lynch et al., 2010; Warrington et al., 2009; Wilson et al., 2014b). NH jockeys reported losing significant greater body mass (2.0 ± 0.1 kg) than their flat racing counterparts. As regard exercise habits, over three quarters of jockeys reported partaking in exercise in addition to 'riding out' in which cardiovascular training was the most commonly reported method to manage body mass, which is in agreement with previous research (Labadarios et al., 1993). Further analysis of exercise habits is warranted with specific reference to recreational exercise versus exercise for performance and weight loss. Of the 42% of jockeys that reported participation in S&C, 33% (n=12) use HIIT training. In contrast to low reported participation rates in S&C, 76% of the surveyed jockeys conveyed that they would welcome S&C support. It is imperative to ascertain the physiological demands of racing for both flat and NH jockeys in order to implement appropriate S&C interventions. With an evident paucity of performance orientated research, Chapter Five investigated the physiological demands of racing for both flat and NH jockeys.

It is 25 years since Trowbridge et al. (1995) highlighted the lack of appropriate literature on the physiological demands of professional jockeys. Only two studies have since been published detailing the physiological demands in flat racing (Cullen et al., 2015; O'Reilly et al., 2017). No study has since been published concerning professional NH jockeys. Given the evident gap in the literature, we sought to investigate the physiological demands of flat and NH racing over two course distance short and long race distances (Chapter Four). Additionally, the study also investigated hydration status and perceived exertion. There was no significant difference between the hydration status of each jockey recorded before flat and NH racing which is a novel finding for the literature and unexpected given the lighter racing weights of flat jockeys. The temperature and humidity were significantly higher during the flat racing data collection in line with expected seasonal differences although these did not appear to alter jockey's physiological responses. While NH jockeys reported significantly greater body mass losses prior to racing (Chapter Four), it did not appear to manifest itself in hydration status. The main finding of study three found no significant difference ($p < 0.05$) between flat and NH racing or any race distance when analysing peak HR or peak blood lactate concentration. However, longer races were associated with greater perceived exertion with a significantly higher RPE reported for the long NH races. The mean HR in the long NH race (151 ± 19 b·min^{-1}) was significantly lower than the mean HR reported in all other race distances for professional jockeys. High physiological output was reported across all race distances with peak HR found to be similar to previously reported values in flat racing (Cullen et al., 2015; O'Reilly et al., 2017) and NH racing (Trowbridge et al., 1995). Results of the studies suggest jockeys experience high metabolic demands in racing with contribution required from both the aerobic and anaerobic systems but this is not accompanied by participation in exercise or training activities that replicate the demands of racing. While the steady state nature of 'riding out' may improve a jockeys aerobic capacity, it does not prepare jockeys for the demands of racing. HIIT elicits a superior response for both VO_2 and HR (Astorino & Schubert, 2014) in comparison to steady-state endurance training undertaken during 'riding out' (Kiely et al., 2019a; Scharhag-Rosenberger, Walitzek, Kindermann, & Meyer, 2012). Additionally, HIIT training will improve both aerobic and anaerobic capacities (Facey et al., 2013; Foster et al., 2015). Suggestions to prescribe a HIIT intervention with jockeys is in alignment with previous research in the area (Cullen et al., 2015). Tests to examine the effectiveness of relevant training interventions are also called for (Cullen et al., 2015). Study four (Chapter Six) focused on the development and test-retest reliability of the Jockey-Fit Testing Battery.

A novel step in the development phase of this thesis was the formation of the testing battery for jockeys. Currently no field test battery exits for professionals to assess jockey fitness or evaluate specific training interventions. Simulator based tests (Cullen et al., 2015; Wilson et al., 2013) and laboratory based maximal aerobic tests (Cullen et al., 2015; O'Reilly et al., 2017) have been utilised while field tests of flexibility, isometric strength and balance (Hitchens et al., 2011a) have also been investigated with jockeys. However, the validity and feasibility of some tests for a jockey cohort were questioned with regard to specificity and relevance of tests with regard a jockeys riding position. Furthermore, no reliability analysis on a physical test or a battery of tests with a jockey cohort has been provided in the literature. In the absence of appropriate, reliable and sensitive tests to ascertain jockey specific conditioning and fitness, the Jockey-Fit Testing Battery was developed. Flexibility, isometric strength, upper body muscular endurance, torso stabilisation and aerobic fitness were identified important physical parameters for racing following an extensive review of the literature however there is scope to investigate the criterion validity of these parameters to racing. Tests were chosen for inclusion in the reliability study based upon an existing body of literature on the reliability of the test, the validity of the test to measure a variable relative to horse racing and feasibility and robustness of the test to be implemented as part of a larger battery within the horse racing industry. Tests that achieved the pre-determined minimum acceptable reliability criteria (ICC > 0.7) were the sit and reach test, IMTP, torso side bridge tests (left & right), revised push up test and Wattbike 3-minute test (VO_{2max} & MMP). While IMTP was reliable to rank the jockey population over two testing days, it is suggested that practitioners run a familiarisation trial to minimise any potential learning effect which is common in fitness test reliability research (Lubans et al., 2011). This may aid the achievement of absolute reliability for the IMTP. All other included tests demonstrated absolute reliability to detect change in performance between tests. The Jockey-Fit Testing Battery is a reliable field testing battery for jockey athletes and can be used in the horse racing industry to assess jockey fitness, monitor the success of specific fitness interventions and profile physical fitness parameters on a national and international basis. Future research is encouraged in the development of an ecologically valid simulator based fitness test.

7.3 Practical applications

The main findings of this thesis have important practical applications for practitioners working with jockey athletes. These applications can be summarised as followed:

- A large majority of jockeys (88%) agree that S&C can improve riding performance yet less than 50% of jockeys partake in S&C. Educational interventions on the benefits of S&C for both riding performance and making weight should be provided by the governing authorities. The major reason cited for non-participation in S&C was insufficient time. Consequently, when programming, practitioners should apply a multi-faceted approach which accounts for the jockey's lifestyle, work and racing commitments when deciding upon exercise loading strategies.

- S&C coaches should consider and provide training stimulus which exceeds the minimum reported values for blood lactate concentration and mean HR values witnessed in both flat (blood lactate > 8.2 mmol·L^{-1}, HR > 79% of lab HR_{peak}) and NH (> 7.4 mmol·L^{-1}, HR > 93% of lab HR_{peak}) racing. All jockeys can be exposed to similar intensities of additional training outside of riding related work. While all races expose jockeys to near maximal intensities in HR and blood lactate concentration, particular attention should also be given to the duration of races with subjective reports indicating increased exertion in longer races.
- HIIT training has been proposed as advantageous to improve jockey performance which reinforces previous recommendations in horse racing (Cullen et al., 2015). Thirty percent of jockeys indicated that they would have a preference for boxing type classes. High intensity boxing intervals may be utilised as an alternate form of training to expose jockeys to the required high intensities of racing.
- Prolonged isometric squatting positions for relevant durations culminating with short high-intensity pushing activities may contribute to the high HR and metabolic drive observed in racing. Over 50% of the physiological demand in dingy sailing has been cited to be from a quasi-isometric response to the isometric sailing position (Spurway, 2007). While the quasi-isometric response hasn't been quantified in horse racing, it is hypothesised to be present and therefore isometric training should be practiced.
- The Jockey-Fit Testing Battery can be used to profile jockey fitness with both Irish and international jockeys. Additionally, it can provide an assessment tool to monitor jockey specific fitness interventions. There is scope for medical teams in horse racing to utilise the Jockey-Fit Testing battery to determine an athlete's fitness against baseline measures following injury. This objective assessment can aid decision making by medical staff as part of the existing return to ride protocols.

7.4 Limitations

This thesis was completed following a systematic four step plan including a narrative review and 3 empirical research studies. While specific limitations have been declared in each empirical chapter (Chapter Four, Five, Six), further limitations should be noted when interpreting the results of this research:

- Study two (Chapter Four) utilised a questionnaire (see appendix B) to report the physical preparation strategies of jockeys. While steps were implemented to enhance the validity (Delphi method - appendix A) and reliability (semi-structured interview style) of the questionnaire, data were not verified a second time to ensure the accuracy of a jockey's recall. A form of qualitative research such as interviews may provide more in-depth information on the physical preparation strategies of jockeys with particular reference to a jockey's rationale for adopting additional exercise strategies.
- The aim of study four (Chapter Six) was to provide a valid and reliable physical fitness testing battery for the horse racing industry. Tests were deliberately restricted to those that could be administered with robustly constructed and transportable equipment. As a consequence, sensitive pieces of equipment that may be more accurate were not used in this research study such as force plates for the measurement of IMTP and lab based gas exchange systems for the measurement of aerobic power. A Watt Bike was used to assess aerobic power. A horse racing simulator would provide a more ecologically valid method to assess this, however current simulators do not expose jockeys to relevant physical stresses or provide physiological feedback without the addition of expensive gas exchange systems.
- The sample in study four (Chapter Six) (n=20) was small, had a narrow age range (17.3 ± 1.3 years) and were in an early career stage (trainee jockeys) when compared to professional jockeys. A larger sample size would facilitate greater reliability with further precision and statistical power. Trainee jockeys have previously been reported to be significantly younger with a greater aerobic capacity than apprentice jockeys who compete in professional races (Cullen et el., 2015). Results, therefore

cannot be generalised to accurately form a representation of professional flat or NH jockeys.

- The reliability study in Chapter Six was administered by four trained testing assistants with a minimum of an undergraduate qualification in a sport science related field. Protocols as described were followed exactly. It is plausible that if future administrational procedures by practitioners are altered, it may reduce the test-retest reliability of the Jockey-Fit Testing Battery. While the revised push up test has demonstrated inter-rater objectivity (Baumgartner et al., 2002), inter-rater reliability was not investigated in the included tests.

7.5 Future recommendations

The current literature on the physical performance of professional jockeys is limited and the scope for further research is vast. Determining the physiological demands of riding requires a mixed approach of field and laboratory testing (Flood, 2018). The following suggestions for future research directions are linked to limitations in both research and practice that have been identified throughout the thesis.

- Jockeys often partake in cultural and archaic methods to prepare for racing (Warrington et al., 2009; Wilson et al., 2015). There is scope to investigate the effect of culture and tradition on the preparatory strategies and performance related habits of current jockeys.
- Educational interventions for jockeys regarding physical preparation methods are warranted. Follow up research should investigate the effectiveness of these educational interventions on the physical preparation strategies of jockeys and adherence to S&C.
- While S&C practices have been widely investigated for most individual and team sports, specific research is required to establish the current practices of S&C coaches working with jockeys.

Jockeys reported working a high number of hours (34 ± 14) in addition to completing numerous races per week (6.9 ± 6.4) with no specific off season. Future research should investigate the feasibility of jockeys accessing S&C services and implementing S&C into their working and racing schedule in conjunction with sport nutrition and sport psychology support services.

The influence of a quasi-isometric is proposed to account for half the metabolic demand of dingy sailing (Spurway, 2007). Comparatively jockeys sustain a prolonged isometric contraction while adopting a semi-squat riding position. In addition, high peak HR and blood lactate concentrations have now been identified in flat and NH racing however, the contribution of a prolonged isometric contraction to the physiological outcomes experienced by jockeys is not well understood and warrants investigation.

- A longitudinal study design should be implemented to identify the effectiveness of a jockey specific training intervention on physical performance outcomes using the Jockey-Fit Testing battery.
- Despite positive steps with the formation of the Jockey-Fit Testing Battery, future studies should look to establish criterion validity of the tests within the battery. To advance the Jockey-Fit Testing Battery, an ecologically valid fitness test using a specifically designed horse racing simulator should be explored. Validity of the simulator based test should be assessed against the relevant physiological demands of racing as denoted in this thesis.
- Research may look to associations between physical testing scores and an objective measure of race riding success. A follow up randomised control trial could then be administered to investigate the outcome of a specific intervention on variables where an association was identified.

7.6 Conclusion

The thesis has contributed several original findings to academia and practice in an area that has been largely ignored. It has been determined that jockeys are exposed to high mean and peak HR values in both flat and NH racing over short and long course distances. The duration and intensity of racing indicate that both the aerobic and anaerobic energy systems contribute to the overall energy demand (Cullen et al., 2015; Trowbridge, 1995). This knowledge is now strengthened with this research and the addition of high post-race blood lactate concentration values for professional flat and NH races which was consistent to all race distances. It is plausible that similar training intensities can be employed with both flat & NH jockeys for specific race durations. Furthermore, this body of work suggests that jockeys are not sufficiently prepared to meet the demands of racing with limited exposure to high intensity training in 'riding out' or S&C. Given the specific high intensity demands denoted, HIIT training may be advantageous to jockeys in addition to the steady state aerobic work experienced while 'riding out'. The Jockey-Fit Testing Battery is a valid and reliable platform to assess future training interventions to assess jockey's fitness while also facilitating fitness profiling on a national and international level. Collectively the results of this thesis have important messages for physical performance practitioners and governing authorities in horse racing. Jockeys are required to exhibit high intensity efforts multiple times a day, several days a week but are not preparing to meet these demands outside of racing. It is plausible that with specific training interventions at advised intensities that jockeys can enhance both their aerobic and anaerobic capacities leading to an improvement in performance and reduction in injury as a result of falls. The thesis comprises the first peer-reviewed research that concurrently investigated the relative racing demands for professional jockeys and jockey's physical preparation strategies for professional racing.

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Appendices

Appendix A. Delphi method and expert scoring rubric for questionnaire validation in Chapter Three.

Delphi Method & Scoring

The goal of this process is to establish a valid questionnaire using the Delphi technique. You have been chosen as an expert in the field to audit our questionnaire. You are asked to review and score each question on its relevance to the relevant section aim(s) using the 0-10 point Likert scale below.

Scoring Round 1

- Following analysis of the audit from all experts, questions will be accepted for the final questionnaire with an average of 70% acceptance or greater.
- Questions will be rejected from the questionnaire if they average 30% or below.
- We ask that if you score a question 4, 5 or 6 out of ten that you please provide an alternative question or an amendment yo u would make to the current question to improve its strength in relation to the section aim. This can be done in the comment box on t he right hand side of the Likert scale. Comments will be used as a basis to update the relevant questions. Only updated versions of t hese questions will be sent out for round two once analysis of all responses is complete.

Scoring Round 2

- Amended questions will be sent out to experts for round two of the Delphi process. Only questions that receive a 70% averag e or higher will be accepted for the final questionnaire. All other questions will be rejected at this point and the final questionnaire will be formed with the inclusion of accepted questions from round 1 and 2.

Study Title:

Physical preparation behaviors of Jockeys

Study Aims:

The aim of this survey is to investigate the current exercise practices of jockeys in addition to the current knowledge of jo ckeys surrounding strength & Conditioning.

Section 1 Objective:
Form descriptive background profiles that may inform exercise trends.

Section 2 Objective:
Identify if Jockeys who must lose weight rapidly consider exercise as a mode to do so.

Section 3 Objectives:
A) Identify jockey exercise practices while quantifying weekly load using an sRPE model. B) Identify reasons that some jockey s may not exercise C) Gain an understanding of jockey warm up practices

Section 4 Objectives:
Gain an understanding of jockeys knowledge, practice and preferences surrounding strength & conditioning.

Section 4B: Objectives:
Increase an understanding around what strength & conditioning services jockeys would like made available in addition to how b est these services are delivered.

		Strongly reject		Please mark each question form 0-10 using an "X"							Strongly Accept			
		0	1	2	3	4	5	6	7	8	9	10	Comment box	
Section 1	Question 1												Question 1	
	Question 2												Question 2	
	Question 3												Question 3	
	Question 4												Question 4	
	Question 5												Question 5	
	Question 6												Question 6	
	Question 7												Question 7	
	Question 8												Question 8	
	Question 9												Question 9	
	Question 10												Question 10	
	Question 11												Question 11	
Section 2	Question 12												Question 12	
	Question 13												Question 13	
	Question 14												Question 14	
Section 3	Question 15												Question 15	
	Question 16												Question 16	
	Question 17												Question 17	
	Question 18												Question 18	
	Question 19												Question 19	
Section 4	Question 20												Question 20	
	Question 21												Question 21	
	Question 22												Question 22	
	Question 23												Question 23	
Section 4B	Question 24												Question 24	
	Question 25												Question 25	
	Question 26												Question 26	
	Question 27												Question 27	
	Question 28												Question 28	
		0	1	2	3	4	5	6	7	8	9	10		

Appendix B. Questionnaire for Chapter Three.

Subject information sheet

Thank you for your interest in this research.

The aim of this survey is to investigate the current training practices of professional jockeys in addition to the current knowledge of jockeys surrounding strength & Conditioning. There are 28 questions in the survey, which include both open and closed ended questions. These questions are broken into five sections; 1) Background information, 2) Making weight, 3) Current exercise habits, 4) Knowledge & practice of Strength & Conditioning, 5) Strength & Conditioning services. Please try and answer each question thoroughly and honestly. This data will have a positive impact on future jockey preparation strategies and the resources available to you. All results will be coded and made anonymous when used for publication or presentation.

As a participant in the survey you have;

1) The right to non-participation and the right to leave the study at any time.

2) The right to anonymity meaning your name will not be used for any part of the study.

3) The right to confidentiality with only the researcher and his supervisor (Dr. Sarahjane Cullen) having access to study information and data.

4) The right to expect that the primary researcher is responsible and well-meaning in all of his actions.

If participants have concerns about this study and wish to contact an independent person, please contact:
Suzanne Kiely, Secretary of the Ethics committee at Waterford Institute of Technology (skiely@wit.ie)

Kind regards,

Michael Kiely

Turf Club Ph.D. Researcher,
Waterford Institute of Technology.
Phone: 0876136407
Email: Mikeykiely@hotmail.com Twitter: @mikeykiely_

Informed Consent

Dear participant,

Please ensure the following statements are correct.

Ø I have read and understood the subject information sheet.

Ø I understand what the project is about, and what the results will be used for.

Ø I currently hold a professional jockey licence.

Ø I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.

Ø I am aware that my results will be kept confidential.

Subject's name: ______________________________

Subject's signature: ______________________________

Parent's signature (If under 18) ______________________________

Date: ______________________________

Researcher's signature: ______________________________

1. Background Information

1. Are you

- [ ] Male
- [ ] Female

2. What age are you in years?

[ ]

3. What category of licence do you race under mostly?

- [ ] Professional Flat licence
- [ ] Professional Jump licence

4. What are you claiming off?

- [ ] 0 lbs
- [ ] 3 lbs
- [ ] 5 lbs
- [ ] 7 lbs
- [ ] 10 lbs

5. How many years have you held your racing licence?

[ ]

6. How many winners have you had?

[ ]

7. During the season how many races do you typically have per week?

- ( ) 1-5
- ( ) 6-10
- ( ) 11-15
- ( ) 16-20
- ( ) 21+

8. What county do you currently live in?

[ ]

9. How long do you typically spend commuting to work on a **NON** racing day (minutes)?

[ ]

10. During the racing season how many hours per week on average do you typically spend completing riding and yard work?

[ ]

2. Making weight

11. Do you ever have difficulty making weight?
If you answer no please skip to section 3.

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

12. How much weight (lbs) do you typically lose to achieve your common racing weight?

13. How often must you rapidly reduce weight to make weight?

- ◯ Daily
- ◯ 2-3 times a week
- ◯ Once a week
- ◯ 2 -3 times a month
- ◯ once a month
- ◯ less than once a month

14. Do you exercise to help with rapid weight loss for racing?

- ◯ No
- ◯ Yes **with** sweat suit
- ◯ Yes **without** sweatsuit

3. Current Exercise Habits

15. Do you exercise outside of riding?
If you answered yes please skip to question 17.

- ◯ Yes
- ◯ No

16. Why do you not exercise outside of riding ? Please tick the most relevant answer for you. Once answered please skip to question 18.

- ◯ I don't have time
- ◯ I am too tired following work
- ◯ I am not aware of classes/ fitness trainers in my locality
- ◯ I am fit enough from riding out
- ◯ I can't afford it
- ◯ Exercise will lead me to put on weight/muscle mass
- ◯ Other (please specify)

17. Please list any exercise activities or sports you participate in weekly during the season?
Please also include the sRPE of this activity as shown on the RPE chart and typically how many times a week you complete this activity.

Exercise/ sRPE/ Times per week completed

Exercise/ sRPE/ Times per week completed

Exercise/ sRPE/ Times per week completed

Exercise/ sRPE/ Times per week completed

Exercise/ sRPE/ Times per week completed

18. Do you warm up before a race?

If you answered no, please move to question 20.

◯ Yes

◯ No

19. Please tick any of type of activity you complete as part of a warm up before racing? Please also indicate the time you spend at this activity.

	0-5 mins	6-10mins	11-15 mins	16-20 mins
Light aerobic exercise (e.g Jogging)	◯	◯	◯	◯
Static Stretching (e.g Hamstring stretch for 10-30 secs)	◯	◯	◯	◯
Dynamic Stretching (e.g Walking lunge held for 1-3 seconds)	◯	◯	◯	◯
Foam Rolling	◯	◯	◯	◯
Glue activation exercises using resistance bands	◯	◯	◯	◯
Massage/Physiotherapy	◯	◯	◯	◯

Other (please also specify time)

4. Knowledge and practice of Strength & Conditioning

20. According to the English Institute of Sport, Strength and Conditioning (S&C) is more than just lifting weights" Have you previously heard of the term or engaged in 'Strength & Conditioning'?

If you answered no, the questionnaire has now ended and we would like to thank you for your time.

◯ Yes

◯ No

21. Strength & Conditioning can:

	I agree	I neither agree or disgree	I disagree
Improve your riding performance	◯	◯	◯
Reduce the risk of injury	◯	◯	◯
Slow your movement down	◯	◯	◯
Help you positively manage your weight	◯	◯	◯
Improve your bone health	◯	◯	◯
Make you too heavy	◯	◯	◯
Improve your balance and overall coordination	◯	◯	◯
Improve your riding posture	◯	◯	◯
Improve your general and specific strength	◯	◯	◯
Improve your general and specific endurance	◯	◯	◯

22. Why do you NOT engage in Strength & Conditioning more regularly ? Please tick the most relevant answer for you.

- ◯ I partake in Strength & Conditioning regularly (once a week or greater)
- ◯ I don't have time
- ◯ I am too tired following work
- ◯ I am not aware of classes/ fitness trainers in my locality
- ◯ I am fit enough from riding out
- ◯ I can't afford it
- ◯ I don't have access to specialist strength & Conditioning information/advice
- ◯ Other (please specify)

23. If you engage in Strength & Conditioning regularly which of the following do you engage in most frequently? If you don't engage once a weak or greater please skip to question 24.

- ◯ Weights training (e.g squats/bench press)
- ◯ High intensity interval training (e.g body weight circuit)
- ◯ Cardio training (e.g jogging)
- ◯ Flexibility training (e.g stretching/foam rolling)
- ◯ Other (please specify)

24. What type of Strength & Conditioning class would most appeal to you?

- ◯ Strength based classes (e.g lifting weights)
- ◯ Cardio based classes (e.g spin)
- ◯ Boxing classes (e.g sparring)
- ◯ Circuit classes (e.g high intensity body weight exercise)
- ◯ Flexibility classes (e.g stretching)
- ◯ Injury prevention classes (e.g completing exercises that reduce injury)
- ◯ Falls training classes
- ◯ Other (please specify)

25. Why would this type of class appeal to you?

26. Where do you source information about Strength & Conditioning practices?

- ◯ I don't source information about strength & conditioning
- ◯ Books
- ◯ Internet
- ◯ Personal Trainer/ Strength & Conditioning Coach
- ◯ Friends
- ◯ Other Jockeys
- ◯ The Jockey Pathway (Horse Racing Ireland)
- ◯ Other (please specify)

27. Would you like more information made available to you about strength & conditioning?

- ◯ Yes
- ◯ No

28. If you answered yes, how would you most like to receive this information?

- ◯ Email
- ◯ S&C classes
- ◯ Online videos
- ◯ Fact sheet
- ◯ A jockey specific training app
- ◯ Lectures or seminars
- ◯ One on one consultation with a strength & conditioning coach
- ◯ Infographics
- ◯ Other (please specify)

Appendix C. Participant information sheet and informed consent forms for chapter Three.

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"Physical preparation Strategies of Jockeys"

Participant Information Sheet

Primary Researcher: Michael Kiely (MSc.)

The aim of this questionnaire is to investigate the current training practices of jockeys in addition to knowledge surrounding strength & Conditioning. There are 28 questions in the questionnaire, which include both open and closed ended questions. These questions are broken into four sections; 1) Background information, 2) Making weight, 3) Current exercise habits, 4) Knowledge & practice of strength & conditioning. Please try and answer each question thoroughly and honestly. This data will have a positive impact on future jockey preparation strategies and the resources available to you. All results will be coded and made anonymous when used for publication or presentation.

As a participant in the survey you have;

1) The right to non-participation and the right to leave the study at any time.
2) The right to anonymity meaning your name will not be used for any part of the study.
3) The right to confidentiality with only the researcher and his supervisor (Dr. Sarahjane Cullen) having access to study information and data.
4) The right to expect that the primary researcher is responsible and well-meaning in all of his actions.

Benefits of participation

The benefits to you of participating in this study are receiving personal feedback physical preparation strategies for racing. This information can inform your daily training regimes to improve your fitness over multiple rides in competitive meetings.

Potential risks to participants from involvement in the research study

All information gathered during this data collection period will be confidential. There are no physical requirements which may cause harm or injury.

Further Information:

As a participant in this study you have the right to withdraw from the study at any time. The findings of this study may be published but your name will not be used in any publication or presentation. You will be supplied with a full copy of your results following analysis. If you have any concerns about this study and wish to contact someone independent from the study, you may contact:

Suzanne Kiely,
Secretary to the Ethics Committee,
Cork Road,
Waterford Institute of Technology,
Co. Waterford.
mailto:skiely@wit.ie

Waterford Institute *of* Technology
INSTITIÚID TEICNEOLAÍOCHTA PHORT LÁIRGE

Informed Consent Form

Investigators involved: Dr SJ Cullen & Dr Giles Warrington (Jockey Research Project Coordinators), Michael Kiely (IHRB Research Fellow), Dr Adrian McGoldrick (Chief Medical Officer IHRB).

"Physical preparation Strategies of Jockeys"

Without knowing the physiological preparation strategies of flat and national hunt horse racing, difficulty arises when suggesting training practices for jockeys. Your participation in filling in a questionnaire as detailed above. The information will be used to inform the physical preparatory strategies of current and future jockeys.

- I have read and understood the subject information sheet.
- I understand what the project is about, and what the results will be used for.
- I understand I must currently hold a professional jockey licence
- I have completed the pre-test screening form.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I am aware that my results are confidential.

Subject's name:	
Subject's signature:	
Parental Signature (if under 18 years)	
Date:	
Experimenter's signature:	

Appendix D. Participant information sheet, and informed consent forms for chapter Four.

"Physiological demands of professional Flat and National Hunt Horse Racing"

Participant Information Sheet

Primary Researcher: Michael Kiely (MSc.)

The aim of this study is to investigate the physical demands that are placed on a jockey over a short and long race. Testing involves a preliminary test and the physical monitoring of two races;

Participant requirements:
You will be required to attend RACE on one occasion before race day to perform a maximal treadmill running test (30 minutes in total). From this we will record your maximal HR and maximal lactate values. On race day, a urine sample will be provided to measure your hydration status and your blood lactate will be measured via a small blood sample from a pin prick to the ear lobe. This will take a maximum of 5 minutes before each race. During racing your heart rate will be measured with a lightweight strap positioned around your chest. Post-racing tests include lactate measurement and you will be asked to provide a perceived exertion score from the race. Again this will take a maximum of 5 minutes after each race.

Participant Responsibilities
Your health status or previous experiences of heart-related symptoms with physical effort may affect the safety of your exercise test and must be reported by you to the chief investigator. The quick reporting of these and any other unusual feelings with effort during the exercise test itself is of great importance. You are responsible for fully disclosing your medical history, as well as symptoms that may occur during the test and any medication you are currently taking

Benefits of participation

The benefits to you of participating in this study are receiving personal feedback on your hydration status before racing in addition to feedback on your physiological performance measures during racing. This information can inform your daily training regimes to improve your fitness over multiple rides in competitive meetings.

Potential risks to participants from involvement in the research study

All procedures involved in this study are standard practice when working with healthy male athletes. In the unlikely event of an injury, first aid will be administered and emergency services will be contacted if necessary. Muscle soreness may be experienced following the maximal test running protocol.

Further Information:

Any questions about the procedures in this study are encouraged. Information, which you possess, about personal health status or previous unusual feelings surrounding physical effort may affect the safety and value of your participation. Your prompt reporting of such feelings are of great important to us. As such you are fully responsible to disclose such health related information to the testing staff.

As a participant in this study you have the right to withdraw from the study at any time. The findings of this study may be published but your name will not be used in any publication or presentation. You will be supplied with a full copy of your results following analysis. If you have any concerns about this study and wish to contact someone independent from the study, you may contact:

Suzanne Kiely,
Secretary to the Ethics Committee,
Cork Road,
Waterford Institute of Technology,
Co. Waterford.
mailto:skiely@wit.ie

Waterford Institute *of* Technology
INSTITIÚID TEICNEOLAÍOCHTA PHORT LÁIRGE

Informed Consent Form

Investigators involved: Dr SJ Cullen & Dr Giles Warrington (Jockey Research Project Coordinators), Michael Kiely (IHRB Research Fellow), Dr Adrian McGoldrick (Medical Officer IHRB), Dr Jennifer Pugh (Chief Medical Officer IHRB).

"Physiological demands of professional Flat and National Hunt Horse Racing"

Without knowing the physiological demands of flat and national hunt horse racing, difficulty arises when suggesting training practices for jockeys. Your participation in this study involves preforming an initial maximal running test. On race day your urine, heart rate and blood lactate concentration will be monitored during a short and long race for your discipline. The information will be used to inform the physical preparatory strategies of current and future jockeys.

- I have read and understood the subject information sheet.
- I understand what the project is about, and what the results will be used for.
- I understand I must currently hold a professional jockey licence
- I have completed the pre-test screening form.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I am aware that my results are confidential.

Subject's name:	
Subject's signature:	
Parental Signature (if under 18 years)	
Date:	
Experimenter's signature:	

Pre Test Screening Form

"Physiological demands of professional Flat and National Hunt Horse Racing"

Any information obtained from you will be treated as confidential

Please tick appropriate box

	Yes	No
Has the test procedure been fully explained to you?		
Has your doctor ever said that you have a heart condition and that you are unable to do certain activities		
Do you feel pain in your chest when you do physical activity or when at rest?		
Do you have a bone, joint or muscle injury that could be made worse by a maximal exertion of effort?		
Is your doctor currently prescribing drugs for your blood pressure or heart condition?		
Do you know of any other reasons why you should not undergo physical activity? This might include severe asthma, diabetes, a recent sports injury, or serious illness.		

If you have answered **NO** to all questions then you can be reasonably sure that you can take part in the physical activity requirement of the test procedure

I ……………………………… declare that the above information is correct at the time of completing this questionnaire

Date ……/……/…….

Please Note: If your health changes so that you can then answer YES to any of the above questions, tell the experimenter/laboratory supervisor. Consult with IHRB doctor regarding the level of physical activity you can conduct

Signature of Experimenter……………………………….. Date ……/……/…….

Appendix E. Participant information sheet, and informed consent forms for Chapter Five.

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"Design and Test-Retest Reliability of the Jockey-Fit Testing Battery."

Participant Information Sheet

Primary Researcher: Michael Kiely (MSc.)

The aim of this study is to investigate the test-retest reliability of a physical testing protocol for jockeys. Each participant is required to perform the same physical testing battery on two separate occasions separated by one week. Each testing day will be approximately 90 minutes in duration. On testing day, height and weight will be first recorded. Your flexibility will be measured using a sit and reach test. Your strength will be measured using a push up test and a mid-thigh pull with a dynamometer while you core endurance will be monitored with the McGill torso test. Finally, your fitness level will be measured with a 3-minute watt bike test.

The benefits to you of participating in this study are receiving personal feedback on your physical performance. This information can inform your daily training regimes to improve your fitness for riding. In addition, your participation will help form a testing protocol which will provide professional jockeys with feedback on their physical performance metrics.

All procedures involved in this study are standard practice when working with healthy athletes. In the unlikely event of an injury, first aid will be administered and emergency services will be contacted if necessary.

Further Information:

Any questions about the procedures in this study are encouraged. Information, which you possess, about personal health status or previous unusual feelings surrounding physical effort may affect the safety and value of your participation. Your prompt reporting of such feelings are of great important to us. As such you are fully responsible to disclose such health related information to the testing staff.

As a participant in this study you have the right to withdraw from the study at any time. The findings of this study may be published but your name will not be used in any publication or presentation. You will be supplied with a full copy of your results following analysis. If you have any concerns about this study and wish to contact someone independent from the study, you may contact:

Suzanne Kiely,
Secretary to the Ethics Committee,
Cork Road,
Waterford Institute of Technology,
Co. Waterford.
mailto:skiely@wit.ie

"Design and Test-Retest Reliability of the Jockey-Fit Testing Battery."

Informed Consent Form

- I have read and understood the subject information sheet.
- I understand what the project is about, and what the results will be used for.
- I understand I must currently be a trainee jockey at RACE academy
- I have completed the pre-test screening form.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I am aware that my results will be kept confidential.

Subject's name:	
Subject's signature:	
Parental Signature (if under 18 years)	
Date:	
Experimenter's signature:	

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"Design and Test-Retest Reliability of the Jockey-Fit Testing Battery."

Pre Test Screening form

Any information contained obtained from you will be treated as confidential

Please tick appropriate box

	Yes	No
Has the test procedure been fully explained to you?		
Has your doctor ever said that you have a heart condition and that you are unable to do certain activities		
Do you feel pain in your chest when you do physical activity or when at rest?		
Do you have a bone, joint or muscle injury that could be made worse by a maximal exertion of effort?		
Is your doctor currently prescribing drugs for your blood pressure or heart condition?		
Do you know of any other reasons why you should not undergo physical activity? This might include severe asthma, diabetes, a recent sports injury, or serious illness.		

If you have answered **NO** to all questions, then you can be reasonably sure that you can take part in the physical activity requirement of the test procedure

I ………………………………. declare that the above information is correct at the time of completing this questionnaire

Date ……/……/…….

Please Note: If your health changes so that you can then answer YES to any of the above questions, tell the experimenter/laboratory supervisor. Consult with IHRB doctor regarding the level of physical activity you can conduct.

Signature of Experimenter……………………………….. Date ……/……/…….

Appendix F. RAMP Warm-up protocol for the Jockey-Fit Testing Battery

RAMP Warm-up Protocol (Jeffreys, 2007)

Warm-up for the Jockey-Fit Testing Battery

Raise — Raise body temperature and increase heart rate

- 5 minute steady jog

Activate — Activate key muscle groups

- Overhead squat (x10 repetitions (reps))
- Bilateral glute bridge (2x15 second hold)

Mobilise — Mobility and stability focus

- Hip hinge with hands on hips (x10 reps)
- Calf pulse (x10 reps each leg)
- Groin rotations (x10 each leg)
- Chest expansions (x10 reps each arm)

Potentiate — Post activation potentiation

- Single leg glute bridge raise (x5 reps each leg)
- Squat jumps (x3 reps)
- Power press up (x3 reps)

Appendix G. Journal Article: Physiological and performance monitoring in competitive sporting environments.

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2019). Physiological and performance monitoring in competitive sporting environments: A review for elite individual sports. *Strength & Conditioning Journal*, *41*(6), 62-74.

Physiological and Performance Monitoring in Competitive Sporting Environments: A Review for Elite Individual Sports

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ABSTRACT

THERE IS A GREAT APPRECIATION FOR THE APPLICATION OF PHYSIOLOGICAL MONITORING WITHIN COMPETITION FOR INDIVIDUAL SPORTS. PHYSIOLOGICAL MONITORING ALLOWS FEEDBACK ON EXERCISE DOSE-RESPONSE, EXERCISE INTENSITY, AND EXERCISE PERFORMANCE. BOTH SUBJECTIVE AND OBJECTIVE PARAMETERS ARE COMMONLY MEASURED IN THE FIELD SPORTS, BUT RESEARCH INVESTIGATING THE ACCURACY AND APPLICABILITY OF MONITORING TOOLS IN A COMPETITIVE ENVIRONMENT FOR INDIVIDUAL ATHLETES IS LIMITED. THIS NARRATIVE REVIEW HIGHLIGHTS THE STRENGTHS AND WEAKNESSES OF INDIVIDUAL DEVICES TO MEASURE A VARIETY OF PARAMETERS, INCLUDING PHYSIOLOGICAL PERFORMANCE, AND BIOCHEMICAL AND SUBJECTIVE PARAMETERS. BASED ON AN ANALYSIS OF THE EXISTING SCIENTIFIC LITERATURE, PRACTICAL APPLICATIONS ARE PROVIDED FOR COACHES.

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INTRODUCTION

Athletes are commonly assessed using a variety of physiological and performance monitoring methods to estimate appropriate training load, screen for overtraining, and empower coaches to match training with the physiological demands of the sport (64,72,110). Individuals can respond differently to the same training or competition stress despite similarities in age, race, sex, and current level of fitness (12,101). Thus, individual monitoring of training and competition dose-response is paramount. Excessive physical stress induced during training and competition can result in disturbances of peripheral and central responses, such as muscle soreness, mood state, biochemical markers, and neural response times (70). The monitoring of athlete activity and training load can provide essential information as to whether an individual is meeting or exceeding optimal functional levels of stress during training and competition (98). Monitoring can also inform athletes, coaches, and support staff on how best to alter training practices to meet competition demands (72).

Internal values require quantification of the physiological stress placed on the athlete with the most common methods to measure exercise intensity by the way of heart rate (HR), various blood biomarkers, and a rating of perceived exertion (RPE) (30,98). External values of training and competition use metrics such as power output via jump performance or distance covered (in meters) (124). Physiological (72), biochemical (120), and subjective measures (99) and jump performance (107) are all potential parameters for individual athlete monitoring; however, their use in competitive sporting environments remains unclear and sparsely researched.

Difficulties arise when monitoring sports performance during competition as a result of a variety of factors, including rules and regulations,

KEY WORDS:
physiological monitoring; biochemical monitoring; subjective monitoring; jump performance monitoring

environmental conditions, and individuality of dose-response mechanisms within athletes. Sports, such as horse racing and combative sports, have strict weight restrictions imposed (35,71,116), which may prohibit the use of monitoring devices that add additional weight. Environmental conditions including the perceived importance of the competition may evoke an anticipatory response for the athlete, which can have an influential physical, motivational, or physiological effect (57). Furthermore, climatic factors, such as an increase in wind and temperature, can modify mean HR while monitoring athletes in competition (57). Although physiological load in high-intensity sports has proven difficult to quantify (41), technological advances in equipment design have made HR and global positioning systems (GPS) popular methods of tracking activity profiles in sport (5,6,8). Although HR has been monitored extensively among individual athletes in competition (95,97,102), there is a paucity of scientific literature relating to the monitoring of other physiological parameters in competition. As not all responses to exercise are physiological, the aim of the review was to investigate common methods used for the assessment of physiological, performance, biochemical, and subjective parameters within a competitive individual sporting environment. These parameters have been presented and applied through a multitude of individual sports assessed in a competitive environment: combat sports, cycling, equine sports, motorsports, racket sports, water sports, track and field, and weightlifting.

PHYSIOLOGICAL MONITORS

Functional tools that incorporate physiological feedback are required to guide training program design by determining both dose-response and intensity of effort during competition (72). Obtaining physiological data has become more attainable with the introduction of HR monitors, accelerometers, GPS units, and integrated technology (IT), which has enabled sports scientists to take physiological performance testing from the laboratory to the field (66,72). However, profiling physiological and performance demands within competition can often prove challenging to quantify because of the constraints imposed by governing bodies.

HEART RATE MONITORING

HR monitors are an accessible and noninvasive tool (102), primarily used to record mean and peak HR (55). Although some individual sports show a large degree of HR variability between and within competition, real-time monitoring is important to estimate the acute physiological load of the event imposed on the participant (85). HR is commonly used to measure exercise intensity by the way of a strap fitted in line with the sternum (63). Electrodes placed on the chest show a mean bias and variability of less than 1.0 beat per minute (69). HR devices have been validated to measure low- and high-intensity exercises (55). Of the most common and most accurate brands, Polar has been reported as a reliable tool to report mean HR (55,68).

Several studies have used HR data in competitive and individual sporting environments. On and off road competitive cycling (102,122), horse racing (84,115), Olympic horse riding (95), competitive sailing, and motorsport (25,97) are just some of the individual athlete sports that have used HR as a measure of intensity in competition (Table 1). Although external environmental factors, such as temperature (51), altitude (28), and overtraining, can affect HR, competition stress must also be considered. Increased secretion of epinephrine during periods of high concentration and technical precision is evident among professional badminton players (19). This increased hormonal reaction may instigate an elevated HR response, more than what is required by the actual physical effort. Competing in a dehydrated state, particularly common in weight-restricted sports (27,125,127), may also influence HR values as a result of cardiac drift (51). A quasi-isometric effect, which is viewed as a metabolic reaction to increased blood flow through areas of enhanced muscular pressure, may also elevate HR (105). This can occur in dingy sailing and horse riding where prolonged isometric stress is placed on the quadriceps, and an increase in HR disproportionate to oxygen consumption is evident. Although specific consideration must be given to competition requirements and environmental factors, HR monitors are perceived user friendly, reliable, and valid to measure exercise intensity response.

GLOBAL POSITIONING SYSTEMS

First established for military purposes (29), GPS now offers quantitative data on the positioning, displacement, and speed of movement of athletes (38) in the air-, sea-, and land-based environments (29). Deferential units with ground-based reference points were initially used for sporting purposes (29); however, in modern times, nondeferential, satellite-based devices are preferred because of reduced device weight and cost (33).

Validity studies in cycling have found GPS to be accurate at both constant and varying speed in linear and nonlinear courses (58,130), although GPS has also been shown to be a valid tool for measuring total distance in activities, such as walking and jogging (33). It is understood that as nonlinear running and the speed of locomotion increases, the validity of the measurements decrease. Therefore, for endurance sports such as long distance running, which produce low-velocity linear movements, the validity of measurements reported can be considered acceptable (37,50,61,88,89).

Manufacturers now produce devices that sample position data at 15 Hz; however, in addition to the sampling frequency, the accuracy of nondeferential GPS units is also largely dependent on satellite signal strength. Highly populated and partially enclosed arenas have been recognized to weaken the GPS signal to the receiver (5,33). This may affect

Table 1
Summary table of physiological monitoring tools reported from competition in elite individual sports

Parameter measured	Device	Research reported from	Advantages	Disadvantages
Heart rate	Heart rate monitor	Road cycling, off road cycling, horse racing, Olympic horse riding, competitive sailing, motorsport	Validated to measure low- and high-intensity exercise Commonly used in competition and individual sporting environments	Temperature and hydration status may affect readings Prolonged isometric efforts can elevate heart rate
Positioning, displacement and speed	Global positioning system	No research is available from competition with individual sport athletes	Compact lightweight device Validity increases over longer distances	Not reliable to measure high-velocity nonlinear movements Signal strength weakens in highly populated or enclosed areas
Frequency and magnitude of movement	Accelerometer	Equine, swimming, tennis	Validated to measure low-intensity exercise Have been used to assess sports skills, such as tennis and swimming strokes	A number of algorithms exist that make comparability of data difficult Unable to distinguish between different types of activity Not suitable for high-intensity activities
Heart rate, respiratory rate, skin temperature, and core temperature	Equivital	Horse racing	Reports data for up to 50 d Light weight device	Has not been validated in sporting environments Elements of the device are not reusable, which may elevate research costs The device is fitted with a generic sized belt
Energy expenditure via combined heart rate and motion analysis data	Actiheart	No research is available from competition with individual sport athletes	Valid and reliable tool for activities of low intensity Lightweight device Contains a rechargeable battery	Individual components of the device must be calibrated individually Not suitable for high-intensity activities
Heat production, biaxial acceleration, and energy expenditure	SenseWear Pro 3 arm band	Table tennis	Can store data for up to 5 d Lightweight device	Not suitable for high-intensity activities A 15-min familiarization period is required with the athlete before the event

(continued)

Table 1 (continued)				
Heart rate, global positioning, frequency and magnitude of movement	Catapult Minimax devices	No research is available from competition with individual sport athletes	Most common tool reported in the literature outside of individual sport Lightweight device Modern devices with greater sampling frequency are reporting with greater accuracy	Not validated to measure high-velocity nonlinear movements Consensus required among researchers for intensity and work load markers

sports such as show jumping, water polo, and some motorsports. Weakened signals can result in miscalculations in distance and displacement calculations within the device (33). To the authors' knowledge, there is no published GPS data or results for indoor sports, whereas the majority of GPS research investigates movements in elite field sports with male populations. Nondeferential units have provided inconclusive findings in the speed and displacement of athletes (33) with particular reference to sports, which require a regular change of velocity and direction.

ACCELEROMETERS

The use of accelerometer-based devices has seen a positive advancement in research (33) with sampling frequencies up to 100 Hz available from devices (113). Accelerometers measure movement of direction in uniaxial and triaxial planes to indicate frequency, duration, and intensity of activity (17,22). Significantly improved estimations of energy expenditure (EE) have now also been developed with raw acceleration data preferred over counts data (113), which tracks the number of times an activity reaches the desired activity threshold. The application of accelerometers has been used in individual sport to estimate EE (128), exercise intensity, and the analysis of skill in sports such as swimming (counts data) (31) and tennis (raw acceleration data) (1).

Accelerometers have been reported to be a valuable tool for activity measurement in many individual sports, including equine (128), swimming (20,31), and tennis (1). Validity studies in physical activity have indicated moderate-to-strong correlations between oxygen consumption and accelerometer counts (r = 0.45–93) (114). However, counts data fail to distinguish between the types of activity with particular problems identified in activities such as cycling and weightlifting where the intensities reported do not match the movement context of the activity (78). Raw acceleration data for sports are thus preferred. Accelerometers have been found to be reliable for measuring physical activity between, but not within, devices during Australian rules games (13); however, such studies in individual sporting competitions remain absent.

The application of accelerometers for the calculation of exercise intensity and EE includes a number of limitations accompanied by analytical challenges (113). Comparability of data collected from sensors worn on different parts of the body is a concern because of weak correlations for exercise intensity and EE (109,113). There is also a greater cost and time requirement for the analysis of data when using wrist worn accelerometers because of the regression equations required to explain the variance of metabolic cost when recording activity intensity from other body sites (109). Further inadequacies exist with varying thresholds and algorithms used in the calculation of intensity by each manufacturer (113). Accelerometers are a valid tool to measure low-intensity exercise; however, limitations exist with regard to high-intensity movements and EE calculations for high-intensity sports. Therefore, practitioners should consider the intensity demands of the sport if considering the use of accelerometry.

INTEGRATED TECHNOLOGY

Equivital life monitor. The Equivital life monitor EQ02 (EQ02; Hidalgo, Cambridge, United Kingdom) is a combination of sensors worn on a chest strap that reports HR, thermal status, respiratory rate via chest expansions, and motion through a triaxial accelerometer. The lightweight device is novel and capable of storing and transmitting real-time physiological and psychophysiological data for up to 50 days (76).

The Equivital has been reported as a valid and reliable tool for the ambulatory monitoring of physiological responses (76). Liu et al. (76) presented strong correlations between HR, respiratory rate, skin temperature, and core temperature using the Equivital tool, but EE calculations can also be estimated. The Equivital has been used in individual competitive sporting environments to monitor jockeys (28); however, to measure EE with this device requires a preexamination step test, which may not be suitable for elite athletes.

The wireless device, which consists of a textile electrode on a universally sized belt, is prone to motion-related disturbances, and this can inhibit R-wave detection during HR monitoring

(81), which is especially problematic in a dynamic sporting environment. Although textile electrodes are used, it is anticipated that greater comfort for the wearer can be experienced with other integrated devices (76). Research cost is an additional limitation of this device because neither the dermal patch nor Jonah pill, an ingestible capsule, is reusable and therefore makes the Equivital an expensive research tool (76). In conclusion, the Equivital is a reliable and valid tool for the recording of low-intensity activities (3); however, cheaper alternatives may be available.

Actiheart. The Actiheart monitor (Actiheart; Cambridge Neurotechnology, Ltd., Cambridge, United Kingdom) measures EE via combined HR and motion analysis and can record physical activity data for up to 21 days. The Actiheart device weighs 10 g, and with an internal rechargeable battery, it provides a light weight device to measure physical activity and EE (22). The device is generally worn on the chest using electrocardiogram (ECG) pads and can monitor HR and EE (14).

Although HR can be used to indicate EE, combining HR and motion analysis may improve the accuracy of EE calculations (15,104). The Actiheart is deemed a valid and reliable tool to measure EE when walking and jogging (14). Although it has been used among individual athletes (129), it was deemed inaccurate when measuring higher-intensity sport as found with both male and female basketball players (96).

To improve the accuracy of data analysis, Spierer et al. (104) proposed that devices are individually calibrated. The accurate measurement of HR and motion analysis is critical to investigate dose-response relationships of exercise in competition. As with other devices, the placement of accelerometers may affect the reliability of data obtained. It has been presented that the Actiheart accelerometer underperforms in comparison to other accelerometer devices placed around the hip area with particular reference to higher-intensity activity, such as level jogging (104). To limit error, the device is best placed underneath the sternum like Polar devices (15), where less contact may also be experienced in individual sports of a contact nature. It is a valid and reliable device for low-intensity activities, but further validation is required with elite athletes in high-intensity sport.

SenseWear Pro 3 armband. The SenseWear Pro 3 armband (Body Media, Pittsburgh, Pennsylvania) is a multifunctioning device worn on the upper arm that can measure heat production, biaxial acceleration, and EE (103). The multisensor device consists of a heat flux sensor, galvanic skin response sensor, a skin temperature sensor, and a near-body ambient temperature sensor (74). Using a 1-minute epoch, the device is capable of collecting and storing physiological data up to 5.5 days (22).

The literature surrounding the device has validated the arm band to estimate EE in low-to-moderate free-living activities (36,43,74); however, it was recently found that the arm band underestimates EE when stepping, walking, and jogging (59,102). In addition, it is advised that the device is used to measure activities at an intensity below 10 metabolic equivalents (METS) (36). Although exercise-specific algorithms may improve the accuracy of the device (59) and the device has been previously used in competitive table tennis (103), further research is required in sports that average greater than 10 METS. Using the compendium of physical activity (2), the practitioner can identify sports that hold a value of 10 METS or greater such as track and field, inline skating, and diving.

The arm band design makes it light weight and suitable to be worn in many sporting environments; however, before data collection, it is suggested by the manufacturer that participants remain in a seated position for a 15-minute familiarization period (59). This would not be possible in many competitive sporting environments where warm-ups are prescribed before the main event. Consisting of multiple sensors, the device overcomes limitations associated with the calculation of EE in single-sensor monitors (43), but there is a requirement for further development of exercise monitoring models (22). It is unknown if the device would be reliable outside of the laboratory in environments that require high-intensity exercise (59,90).

Catapult Minimax devices. Although definitions vary, Dellaserra et al. (33) have defined IT as the inclusion of a GPS unit, HR monitor, and an accelerometer in a singular device. Manufacturers also claim to accurately report impact forces using accelerometer data via *g*-force (106). Catapult Innovations have designed compact, lightweight, and durable devices for impact sports using frequencies up to 15 Hz. The MinmaxX series are the most common tool used in training and cited in the literature (33).

Catapult has validated their devices working with individuals in team games for long distance, low-intensity movements (33); however, no such studies have been published in individual sports within competition. It is understood that 5 Hz offer greater accuracy and reliability when quantifying higher-velocity movements than 1 Hz units (60), but it is not clear whether the 10 Hz MinimaxX V4.0 device improves accuracy in nonlinear high-velocity movements in comparison to the 5 Hz V2.0 units, both of which weigh approximately 67 g (121). When monitoring high-velocity sprint efforts, it must be considered that when using IT devices, each element of the device must be calibrated in tangent and on the same timing or their reliability and validity may be reduced (6,33). With regard to collision parameters, integrated GPS technology does not allow for the precise quantification of impact forces (106).

For practitioners, there are barriers to collecting reliable data. Currently, certain governing bodies in swimming, tennis, and certain soccer organizations prohibit device usage in competition (33). Even though some of the soccer-related research is collected from a competitive environment, there is a need for consensus among team-based researchers for intensity and workload markers, which may aid validation of the tools for all sports (29). In summary, the literature surrounding HR, GPS, accelerometers, and IT is dominated by 2 domains: low-intensity physical activity research in normal populations and elite male athletes in various soccer codes (29). Much research is therefore required in high-intensity activities and individual sports.

BIOCHEMICAL MONITORING

BLOOD LACTATE

Blood lactate concentration $[La^-]_b$ values have been previously recorded as an indicator of metabolic fatigue in individual sports in elite and subelite categories (Table 2) (39,118,120). In addition to monitoring fatigue, blood lactate has been used to analyze longitudinal fluctuations in aerobic and anaerobic fitness (39). The Lactate PRO (Akray, Nakagyo-ku, Kyoto-shi, Japan) is a device that has outperformed a large number of analyzers when compared with the criterion enzymatic method (7,48,91).

The sites from which blood is measured (ear lobe, fingertips), as well as the device and blood sample, can affect the test results (39). The Lactate PRO does not require pipetting of blood, which reduces the chance of experimental error, whereas only a small blood sample of 5 μL is required on the reagent strip for analysis. In terms of accuracy of site samples, samples taken from the earlobe have consistently shown lower blood lactate concentration than those taken from the fingertip (39). However, sufficient concentrations at both sites deem the lactate PRO and the newer lactate plus, a valid and reliable tool to measure lactate concentration in all sporting disciplines (91,111).

As many sports require frequent use of the hands with some athletes required to wear gloves, lactate samples taken from capillary blood by a hyperemized ear lobe is a common field approach (24,57,91). Although lactate can rise progressively during an incremental test to volitional exhaustion or an exercise bout, peak lactate values are generally seen between 3 and 8 minutes post event (48). As with other physiological tools, external and internal

Table 2
Summary table of biochemical monitoring tools reported from competition in elite individual sports

Parameters measured	Device	Research reported from	Advantages	Disadvantages
Blood lactate	Lactate PRO	Triathletes, jockeys, cyclists	Valid and reliable tool to measure all intensity levels Does not require pipetting of blood, providing quick and easily accessible readings	Temperature and hydration status may affect readings Comparability of data between sports is compromised because of alterations in muscle mass
Cortisol	Human Elisa Kits	Tae Kwon Do, downhill mountain biking, swimming	Valid and reliable tool Simple and noninvasive method Provides a psychophysiological response	Serum levels are not consistent throughout the day Rapid weight change can significantly alter cortisol serum levels Food, caffeine, estrogens, and antiinflammatory medication may affect the accuracy of readings
Immunoglobulin A	BN ProSpec analyzer	Swimming, Paralympic swimming, Tae Kwon Do	Reliable biomarker for the detection of infection May indicate periods of overtraining or inadequate recovery	Eating and drinking can dilute sample concentration Large variability reported between and within subjects. High-intensity exercise and anxiety may cause a reduction in flow rate
Alpha-amylase	Soma Science oral fluid collector kits	Paralympic swimming, Tae Kwon Do	Strongly correlated with blood lactate and immunoglobulin A concentrations Has potential to be used as an indicator of competition stress	Acute studies dominate the literature The presence of cortisol can decrease the production of alpha-amylase

environmental factors need to be considered; ambient temperature and hydration status may affect the interpretation of lactate concentration data (12). Dehydration causing a body mass reduction of 3.9% has resulted in a subsequent increase in skeletal muscle lactate concentration (47). Furthermore, practitioners must note that if comparing sports, the mode of exercise can affect lactate accumulation because of alterations of muscle mass (108) as would be seen between running and cycling. If comparing individual athletes within the same sport, training status and training load have both been proposed to affect maximal and submaximal lactate concentrations (62,119) and therefore must be considered during data collection.

SALIVARY BIOMARKERS

Cortisol. Salivary cortisol (an immunosuppressive hormone) is thought to be the main protein for catabolic processes in skeletal muscle because it decreases protein synthesis (123). The hormone has been used to monitor steroid, peptide, and immune markers in sport (87). It has been measured as a psychophysiological response in a multitude of individual disciplines including equine, motorsports, and swimming (95,100,102). Salivary cortisol can be used to determine psychophysiological response in single and repeated exercise bouts (102); however, the literature suggests that no single hormone can specify overtraining syndrome (119).

Cortisol (in nanogram per milliliter) has commonly been measured in the research using commercially available Elisa kits (ELISA SLV-2930; DRG Instruments GmbH, Marburg, Germany). A variety of individual sports have used the kit for the analysis of cortisol via swab, including Tae Kwon Do (116), downhill mountain biking (102), swimming (46), and Paralympic swimming (100). Furthermore, significant correlations have been found between salivary cortisol levels and blood concentration levels, proving the tool to be an accurate method of measurement (75,87). In addition to using a swab, "individual profiling" and "passive drool" point-of-care modalities for salivary sampling are valid and reliable (40).

The assay of salivary cortisol involves a simple and noninvasive protocol in determining the physiological responses of elite athletes in competition (116). Akin to other physiological variables, individual athletes of a well-trained or elite standard can display large rhythmic changes in a 24-hour period (34,126). Cortisol secretion peaks in the early morning after waking and serum levels decrease after this time. It is therefore advisable that in repeated clinical and field trials that consistent data collection time points are considered to avoid misinterpretation of results (65,126). Other limitations and confounding factors must also be considered. For example, Tsai et al. (116) discovered that rapid weight change for combative athletes in addition to high-intensity training significantly decreased cortisol in the 4 weeks before competition. The quality of sample collected in both clinical and sports settings are largely dependent on the protocol used, and it is advised that no smoking, eating, or drinking fluids, which contain fruit juices or caffeine, are consumed 30 minutes before testing to avoid sample contamination (65). At a biochemical level, estrogens, oral contraceptives, and the menstrual cycle are also known to affect the binding of cortisol (53). Corticosteroids found in antiinflammatory medications to treat conditions, such as asthma, back pain, or inflammation, may also have the potential to cross-react with antibodies in immunoassays used to assess salivary cortisol (49). From a practical perspective, it is therefore important that practitioners have an understanding of athlete's medicinal and dietary intake before data collection to avoid a skewed depiction of results.

Alpha-amylase. Salivary α-amylase is the overriding enzyme in saliva. Like cortisol, α-amylase has been used as a biomarker of physical stress response to exercise and sympathetic nervous system activity (10). Collected using an oral fluid collector kit (100), α-amylase is thought to be a more sensitive biomarker than cortisol because it is produced in the salivary glands rather than being transported from blood to saliva as in the case of cortisol. The protein has been monitored during competition in individual sport within a competition environment (100).

Alpha-amylase correlates strongly with anaerobic threshold while running in a noncompetitive environment (21), although a strong correlation was also found between blood lactate values and α-amylase during competition for Tae Kwon Do athletes (23). This may indicate its potential use as an intensity marker in training and competition.

Alpha-amylase has been used acutely within competition for individual athletes. However, its ability as a biomarker of fatigue, illness, or performance in a chronic capacity following competition requires further investigation (87). It is also understood that increases in salivary cortisol are associated with decreases in the production and concentration of salivary immunoglobulin A (IgA) (52). Although the presented biochemical markers can detect immunosuppressant hormones, which may cause a reduction in performance (92), very few studies actually link exercise-induced immune depression and increased incidence of confirmed illness in athletes (45).

Immunoglobulin A. Secreted in saliva, IgA acts in defense against infection of the upper respiratory tract with prior research reporting an inverse relationship between salivary IgA levels and incidence of illness in athletes (45). Changes in salivary IgA levels may also indicate periods of insufficient recovery or excessive training (73,87). Reporting of salivary IgA levels can be in terms of absolute concentrations or secretion rate (87).

Measured in competition during individual sports (73), IgA has been found to be a reliable biomarker for identifying risk of infection in elite athletes, analyzed by a BN ProSpec analyzer (82). Large between- and within-subject variability is evident with particular reference to basal values (82). Furthermore, within-subject variability has also been shown to be greater in elite populations in contrast to recreationally and sedentary populations (42). As basal IgA values are specific to the individual, a relatively large number of samples are required to establish reliable baseline values (82). The most significant method of collecting data seems to be salivary IgA secretion rate because it takes into account flow rate and represents the accurate quantity of salivary IgA available in the saliva (87).

Although generally not lower than normal populations, elite athletes can experience lower salivary IgA levels during intense and heavy training periods (44). It is advised that in addition to measuring IgA, a subjective monitoring questionnaire may provide further information into the fatigue status of the athlete (82).

JUMP PERFORMANCE MONITORING

Pre- and postevent jump height may provide valuable data in relation to exercise intensity and athlete neuromuscular fatigue (77,79). Immediate postexercise performance reductions are associated with maximal exertions in individual sports, which include repeated vertical jumps and also non-weight bearing sports such as cycling (18). It is thought that fatigue is characterized by a loss of force and muscle contraction speed (9,83), and in addition, countermovement jump (CMJ) tests are understood to be sensitive to small alterations in leg-extensor force-generating capacity caused by neuromuscular and muscular fatigue (94).

High test-retest reliability scores for CMJ have been reported (77,93,94) with Markovic et al. (77) reporting a reliability score of 0.98 ($P < 0.01$). CMJ also has a high reliability score compared with other jump tests and is the most valid test for the approximation of explosive power of the lower limbs (77). The commonly used squat and depth jump from a 30-cm height both scored lower in reliability than CMJ (26,77). Although force plates provide a gold standard method to measure flight time and the Optojump photoelectric cells also provide valid and reliable measurements (4), the Chronojump-Bosco system (Chronjump-Bosco system; Chronojump, Barcelona, Spain) jump mat is a valid tool and a cheaper alternative for coaches at all levels. Used for recording jump heights in both male and female athletes, the Chronojump-Bosco system has a relative moderate reliability for testing CMJ in male subjects, although a high relative reliability for female subjects was reported (86).

Although test-retest reliability to measure jump height is high, it is debated whether CMJ is an accurate monitoring tool for the detection of fatigue post event (18). With this in mind, tests, which measure rate of force development, may provide an alternative to monitor neuromuscular fatigue pre and postcompetitive event. The effectiveness of jump performance to measure rate of force development is debated within the literature (80). Vertical stiffness may provide an alternative parameter to measure neuromuscular fatigue with particular reference to sports that require vertical movements (16). Furthermore, it may be important for athletes who run in their respective sports to retain vertical stiffness to use stored elastic energy (16). The measurement of vertical stiffness, as shown by Butler et al. (16), may have a role to play in monitoring performance; the method proposed using a force plate and dividing the peak vertical ground reaction force by the maximal vertical displacement of the center of mass during ground contact. No direct relationship is associated between vertical stiffness and injury but decrements in performance from a baseline measure may indicate fatigue and reduced running economy (67). Although this is a valid measure of vertical stiffness (16), the use of a force plate and the related calculus may prove time consuming for the practitioner during competition.

In a competitive environment, Hoffman et al. (56) found that fatigue could not be detected immediately post the exercise bout as power output is maintained. This may be because of the absence of acute muscle soreness (18) or as suggested by Tillin and Bishop (112), the potential that fatigue subsides at a faster rate than postactivation potentiation following high-intensity activity. However, in lower-intensity activity, it was found that jump height in triathletes significantly decreased post race (107), indicating that sensitivity exists between high- and low-intensity sporting codes. CMJ measured via the Chronojump system is a reliable tool to measure jump height; nevertheless, it is advised that a common landing strategy is adopted (77). The validity of the CMJ to measure post event fatigue is debated in the literature with particular reference to high-intensity sport, so further research is required for its use in fatigue detection. From a practical perspective, jump tests, which monitor performance or fatigue, are easily administered and induce relatively minor fatigue to the athlete (117).

SUBJECTIVE MONITORING

The most widely accepted subjective tool for the assessment of physiological responses to training and competition is RPE using the Borg scale (11). Foster et al. (41) developed an extension of the RPE method, which was entitled the session RPE (sRPE) method (RPE score of a session [1–10] × duration in minutes). This modification of the Borg category ratio 10 scale (CR10) (11) may be a more effective method to calculate exercise intensity and the subjective physiological load of an event. Although other Likert scales exist such as the original 6-20 rating Borg scale RPE scale (11), the sRPE approach is now considered a common standard method of calculating perceived effort and load (32).

sRPE is an accurate tool to minimize undesired training effects by manipulating training loads in response to ratings and is a proven subjective approach to quantify exercise intensity (32,54). For both endurance and high-intensity intermittent sports, the sRPE method of calculating training load and training intensity is considered a valid measure (41) with an intraclass correlation coefficient of 0.88 when investigating high-, moderate-, and low-intensity sessions (32,54). Additionally, sRPE correlates closely with internal measures of training load (26,41) along with objective measures of training intensity (54).

The sRPE method of calculating training intensity is a proven methodological approach in a training environment; however, it has not been validated in a competition environment with individual athletes. There are few limitations presented in the research, but Wallace et al. (124) and Scott et al. (99) recently reported a high measurement error when reporting with a 0-10 RPE scale for long and short bouts of running. Current research is based upon populations from endurance-based sports. Further research of the sRPE method in competitive environments is warranted to determine its validity in reporting competition-related stress in athletes. From a practical perspective, athletes should submit RPE scores in isolation to avoid any selection bias based on other athletes' scores. Furthermore, athletes should submit their RPE score after acute fatigue has dissipated, as the score may be reflective of the last exertion rather than a score reflective of the session intensity as a whole. Between 10 and 30 minutes is recommend after exercise for reporting RPE scores (109).

PRACTICAL APPLICATIONS

Although many monitoring devices provide informative data, the practitioner must consider their applicability in their chosen environment. For devices to be effective in an elite setting, the monitoring tool must be user friendly and time efficient while also ensuring it does not negatively affect the athlete's preperformance routine. If the device is to be worn during completion, the coach should ensure that the device is comfortable for the athlete, and it is permitted to be worn by the regulatory authorities. Devices that provide the practitioner with pre- and postevent measures, such as those discussed under biochemical and jump performance sections, can provide the coach with valid data. A knowledge of the competition requirements should, however, underpin physiological and performance monitoring to ensure that practitioners collect data, which is consistent over multiple time points in a competition setting. It is advisable that coaches document the exact protocols that they will use in each testing session to ensure that a standardized and comparable monitoring environment is created. This is also applicable to subjective measures such as sRPE.

Practitioners must also be cognizant of implications involving the individuality of an athlete particularly with regard to variations in exercise dose-response. It is important that coaches are aware of these variations when performing data analyses and data comparisons on a number of individual athletes. Internal and external factors, such as hydration status, nutritional and medicinal intake, climate and psychological status, should be noted both in preparation for and during the completion to provide background information on the data. Such an approach will ensure that results from one monitoring session can be compared with subsequent or previous data to assess if any worthwhile change has ensued.

SUMMARY

A number of monitoring tools (i.e., HR, GPS, IT, biochemical, jump performance, subjective responses) may provide reliable and valid data for experimental purposes, including exercise dose-response, exercise intensity, and exercise performance. Although it is clear that further research is required in both individual and competitive sporting environments, other informative developments have emerged from this review: (a) Further validation and research of devices for sports that exhibit high-intensity and nonlinear movement patterns are necessary. (b) Practical considerations in the design of devices for competitive environments, such as device weight, comfort, and the placement of devices demand attention. (c) Future studies that measure the specificity of competition demands and known physiology are required to enhance our ability to guide athletic training in individual sports.

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Appendix H. Journal Article: Physical Preparation Strategies of Professional Jockeys

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2020). Physical Preparation Strategies of Professional Jockeys. *Journal of strength and conditioning research*.

Original Research

Journal of Strength and Conditioning Research™

Physical Preparation Strategies of Professional Jockeys

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Abstract

Kiely, M, Warrington, G, McGoldrick, A, and Cullen, S. Physical preparation strategies of professional jockeys. *J Strength Cond Res* XX(X): 000–000, 2019—Professional horse racing is a physically demanding sport. The aim of the study was to examine the physical preparation strategies of jockeys for racing. A questionnaire was developed and validated which comprised of 4 sections; (a) background information, (b) making weight and current associated exercise habits, (c) current physical activity practices, and (d) jockey perceptions of strength and conditioning (S&C) and current practices. Eighty-five jockeys (n = 38 professional flat, n = 47 professional jump) completed the questionnaire in race course weighing rooms representing 80% of the professional athlete population. In total, 77.6% of jockeys participate in physical activity outside of riding. Jockeys that participated in S&C (42.4%) reported their most frequent type of S&C practice; cardio (52.8%), high-intensity interval training (33.3%), flexibility and mobility training (8.3%), resistance training (5.6%). There was no significant difference in S&C participation between total flat and total jump licenses (p = 0.530; |PHI| = 0.068). Difficulty making weight was reported by 55.3% of jockeys. Exercise alone was used by 29.4% of jockeys to rapidly reduce weight. There was no significant difference (p = 0.201, |PHI| = 0.357) between the frequency of rapid weight loss per month for total flat (1.7 ± 1.7) and total jump jockeys (1.6 ± 0.5). This study represents the only published data on the physical preparation strategies of jockeys. Jockeys do not partake in physical activity, which mimics the repeated high-intensity demands of racing. Future research is required to examine the effects of specific S&C interventions on riding performance.

Key Words: horse racing, making weight, strength and conditioning, elite sport

Introduction

Horse racing has been identified as a physically demanding sport (7,30). Jockeys partake in either flat racing or national hunt racing, which take place over jumps. Each license type consists of 2 subcategories; professional flat license or apprentice flat license (less experienced) and professional jump license or conditional jump license (less experienced). Flat racing is held over course distances of 1,000–3,000 m with prerace weight requirements of 52.7–64 kg. National hunt racing also known as jump racing takes place in course distances ranging from 3,200 up to 7,000 m. Jockeys can afford to be heavier in this category with the weight requirement ranging from 62 to 76 kg (7). Because jockeys must exercise close to their physiological capacity (7,30), while maintaining low body mass, high levels of aerobic and anaerobic power are required to be successful (7). Currently, licensed jockeys may be required to compete multiple times a day, up to 7 days a week, with no specific off-season (10). In preparing jockeys to meet the demands of racing, it can be expected that jockeys experience faster recovery rates by reducing fatigue between races and in addition, a greater aerobic capacity may reduce the risk of falls and resulting injury (20,33). Daily riding work of jockeys has been suggested as insufficient to meet the physiological demands of racing, highlighting the importance of performing additional training (23).

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Several studies have investigated strength and conditioning (S&C) training practices, across a range of sports including swimming (2), American football (12), baseball (11), rowing (18) and Rugby union (21,32). These studies provide a comprehensive overview of current S&C practices in addition to providing a reference point for applied practitioners (21). In addition to sports performance benefits, there are positive effects of resistance training on health-related measures including body composition, bone health, and a reduction in sports-related injuries (13). Despite the associated benefits, it is unknown whether jockeys complete basic and less complex weight training or indeed complete any S&C practices in addition to their daily riding work.

Gaining an understanding of jockeys' current physical preparation strategies for racing will allow coaches and governing authorities to facilitate specific training modalities with appropriate physiological demands to optimally prepare jockeys for racing. Subsequently, quantifying typical jockey physical training practices will allow coaches and jockeys alike to plan for optimal performance and individualize training regimes (16,26). Therefore, the aim of the study was to investigate the current physical preparation strategies of jockeys during the racing season.

Methods

Experimental Approach to the Problem

A questionnaire was devised to explore the training habits and preparation strategies of professional jockeys. The research was framed in the context of a research question rather than a prominent hypothesis. The questionnaire was broken into 4 sections comprising a total of 27 questions and was circulated to professional jockeys in person at various racecourse-weighing rooms. Prior approval for the study was granted by the Irish Horse Racing Regulatory Board, the regulatory authority for Irish horse racing.

Subjects

Eighty-five professional jockeys participated in the study ($n = 3$ women, $n = 82$ men). Subjects included 38 professional flat jockeys (professional $n = 16$; apprentice $n = 22$) and 47 professional jump jockeys (professional $n = 27$; conditional $n = 20$). A priori power analysis indicated that a total of 52 subjects would be needed to have 80% power for detecting a large-sized effect ($d = 0.8$) (14). Ethical approval for the study was obtained from the review board of research compliance at the Waterford Institute of Technology and all procedures were in accordance with the Declaration of Helsinki. All subjects were informed that their participation in the study was voluntary. Written informed consent documents were signed and gathered for all subjects before completion of the questionnaire.

Procedures

The questionnaire was circulated to jockeys at race courses with an introductory letter explaining the aims and objectives of the proposed research study in paper format. Race meetings were attended and questionnaires were filled out using a semi-structured interview style by the same researcher to clarify any ambiguities. This was completed in the jockey weighing room before and between races at the jockey's convenience. At the time of completing the questionnaires, jump jockeys were at the end of their season, whereas flat jockeys were at the beginning of their season.

Questionnaire. The questionnaire entitled, "The physical preparation strategies of professional jockeys," template was developed through a commercially available online questionnaire generator (Survey Monkey, Inc., San Mateo, CA) and included 27 questions incorporating open- and closed-ended questions. The questionnaire was divided into 4 sections: (a) Background information; this section detailed information on personal demographics, individual licensing, and racing & working commitments, (b) Making weight and current associated exercise habits; the aim of this section was to identify the prevalence and magnitude of rapid weight loss which was defined as weight lost over a period equal to or less than 24 hours. In addition, the use of exercise as a weight loss tool was investigated, (c) Current physical activity habits; the objective of this section was to quantify and describe jockeys exercise patterns outside of riding-related work. Perceptual load of each exercise session was calculated using the Session "Rate of Perceived Exertion" (sRPE) Method. These sessions referred to exercise sessions outside of riding-related activity that jockeys recalled as a weekly occurrence throughout the racing season. Session rate of perceived exertion of a session is calculated by multiplying the intensity of the sessions (Borg CR-10 scale) by the session duration in minutes, and (d) Practice & perceptions of S&C; the aim of this section was to gain an understanding of jockeys knowledge, practice and preferences surrounding S&C in addition to S&C services they would like provided. For the purpose of data collection and analysis, S&C was defined as any specific physical training that was used to improve riding performance outside of riding-related work. Physical activity was defined as any exercise completed where the aim was not improving riding performance.

To validate the questionnaire, a 2-round iterative Delphi consensus method was administered (29). The questionnaire was circulated via email to 14 individuals with an introductory letter explaining the aims and objectives of the proposed research study and Delphi method. These individuals were selected based on previous academic publications in the area of jockey health and performance, qualitative research or both. Eleven individuals responded and they were asked to review and score each question on its relevance to the study aim using a 0–10 point (0 = no relevance; 10 = highly relevant) Likert scale (1). Following analysis of the audit from all individuals, questions were accepted for the final questionnaire with an average of 70% acceptance or greater in line with previous research (28). Questions were rejected from the questionnaire if they averaged 30% or below. Comments from the review panel were welcomed to improve the questions in relation to appropriateness to the study aim. A reoccurring suggestion from 2 or more of the panel to the wording or format of questions were applied. All questions were accepted following analysis of round one scores and it was not necessary for the questionnaire to enter round 2. The experts were sent the accepted questionnaire after this point.

Statistical Analyses

Data were analyzed using SPSS (Statistical Package for the Social Sciences V22.0; SPSS, Inc, Chicago, IL). Descriptive analysis was the primary form of quantitative analysis which was conducted on closed-ended questions while thematic analysis was applied to open-ended questions. Data were assessed for normality using a Shapiro-Wilk test and descriptive data were presented as mean and standard deviation (mean ± *SD*) with a 95% confidence interval (95% CI). A Mann-Whitmey *U* test was administered to research differences between total flat and total jump jockeys for non-parametric data, whereas independent T-Tests were administered for parametric data. Effect sizes (ESs) for between-group differences were calculated using Cohen's d with $d = 0.2$ considered a "small" ES, 0.5 represents a "medium" ES and 0.8 a "large" ES (4). A one-way analysis of variance and tukey post-hoc test were administered to investigate whether any difference existed between subcategories of the jockey license (flat, apprentice, jump, and conditional). A kruskall-wallis with pairwise comparisons was used to examine whether any difference existed between groups where data were not normally distributed. In this instance, Eta squared was used to quantify ESs. To explore whether any relationship existed between activity parameters and background information, a Pearson product moment correlation was administered. In the case of 2 nominal variables, a Pearson chi squared test of association was administered. A phi coefficient (PHI) was used to interpret the strength of association. Statistical significance was accepted at an alpha level of $p \leq 0.05$. Thematic analysis was applied to the open-ended questions, following the guidelines set out by Braun and Clarke (3) which include 6 phases; (a) familiarization with the data, (b) generating codes, (c) searching for themes, (d) reviewing themes, (e) defining and naming themes, and (f) producing the report.

Results

Background Information

Background information for flat and jump jockeys in addition to a breakdown of license subcategories are reported in Table 1. Jockeys were working average weekly hours of 34 ± 14 in addition to race riding. Professional flat jockeys held their license for greater years and experienced a significantly higher number of winners than other jockeys ($p \leq 0.05$) as reported in Table 1.

Making Weight and Associated Exercise Habits

Difficulty surrounding weight management was reported by 55.3% ($n = 47$) of jockeys. The typical amount of weight loss (kg) of jockeys before racing was significantly different among total flat (1.4 ± 0.6 kg, 95% CI; 1.2–1.7) and total jump jockeys (2.0 ± 0.1 kg, 95% CI; 1.7–2.3) ($p = 0.007$, ES = 1.39 [large]). The associations in license subcategories were located between apprentice (1.3 ± 0.6 kg, 95% CI; 1.1–1.6) and conditional licenses (2.0 ± 0.7 kg, 95% CI; 1.6–2.3) ($p = 0.01$, ES = 1.07 [large]) and apprentice-professional jump licenses (2.0 ± 0.8 kg, 95% CI; 1.5–2.4) ($p = 0.02$, ES = 0.98 [large]). No relationships existed between age and weight loss amount ($r = 0.141$; $p = 0.306$).

Sixty-seven percent of jockeys reported that they rapidly lose weight at least once a month to race. There was no significant association ($p = 0.201$, [PHI] = 0.357) between the frequency of weight loss per month for total flat (1.7 ± 1.7, 95% CI; 1.1–2.3) and total jump jockeys (1.6 ± 0.5, 95% CI; 1.4–1.9). A significant association was located between professional flat and professional jump sublicenses ($p = 0.018$, [PHI] = 0.710). Mean rapid weight loss frequency for each subcategory were; professional flat (1.0 ± 0.5, 95% CI; 0.8–1.3), professional jump (1.6 ± 0.8, 95% CI; 1.2–2.1), apprentice (2.2 ± 2.2, 95% CI; 1.1–3.2), and conditional (1.4 ± 0.5, 95% CI; 1.3–1.8).

There was a significant relationship between jockeys who experience difficulty making weight and those who reported that they partake in physical activity outside of riding ($p = 0.001$, [PHI] = 0.370). Jockeys reported the use of exercise as a method to rapidly reduce body weight; 29.4% ($n = 25$) used exercise alone, 32.9% ($n = 28$) used a sweat suit while exercising, 4.7% ($n = 4$) reported always using a sweat suit while exercising, and 2.4% ($n = 2$) did not use exercise for weight loss.

Current Physical Activity Habits

The jockeys were asked to report their current physical activity levels outside of riding related work. Sixty-six jockeys (77.6%) reported they partake in other physical activity, whereas 22.4% ($n = 19$) jockeys reported no physical activity outside of riding-related work. There was no significant association between total flat (44.7%) and total jump licenses (55.3%) ($p = 0.067$, [PHI] = 0.198) or between licensed subcategories ($p = 0.052$, [PHI] = 0.302). The jockeys were asked to detail the physical activities they partake in using self-recall. Five common themes emerged: (a) cardio, (b) gym-based training, (c) golf, (d) boxing, and (e) field-based games. The participation percentage and frequency of participation in physical activity per week in addition to a weekly sRPE (rated perceived exertion × time [m]) of these activities are represented in Table 2. There was a nonsignificant relationship between both weekly sRPE and age ($r = -0.138$; $p = 0.476$), and weekly sRPE and jockey license ($r = -0.279$; $p = 0.142$).

Table 1

Background data of flat and jump jockeys with a breakdown of license subcategories.*†

	Flat total ($n = 38$)	Jump total ($n = 47$)	Professional flat ($n = 16$)	Apprentice flat ($n = 22$)	Professional jump ($n = 27$)	Conditional jump ($n = 20$)	Total ($n = 85$)
Age (y)							
Mean ± SD	24.6 ± 9.2	26.0 ± 5.1	¶#31.4 ± 10.6	§¶19.6 ± 2.9	¶27.6 ± 5.7	§23.9 ± 3.4	25.4 ± 7.2
Years licence held							
Mean ± SD	8.2 ± 9.6	8.0 ± 5.4	¶#15.4 ± 11.1	§‖3.0 ± 2.0	¶#10.4 ± 5.8	§‖4.7 ± 2.7	8.1 ± 7.5
No. of races per wk							
Mean ± SD	9.4 ± 8.4	6.9 ± 6.3	‡16.3 ± 8.7	§5.9 ± 2.9	§5.4 ± 3.0	§3.5 ± 1.8	6.9 ± 6.4
95% CI	6.73–12.07	5.1–8.7	12.0–20.6	4.7–7.1	3.2–6.7	2.7–4.3	5.5–8.3
Hours worked per wk							
Mean ± SD	29.7 ± 12.4	34.0 ± 14.0	#27.7 ± 16.0	31.2 ± 13.3	35.2 ± 27.0	§40.6 ± 13.2	34.0 ± 14.0
95% CI	25.8–33.6	30.0–38.0	19.9–35.6	25.6–36.8	25.0–45.4	34.8–46.4	31.0–37.0
No. of winners							
Median	214.1 ± 335.1	102.5 ± 174.9	‡460.0	§7.5	§95.0	§14.0	49.0
IQR	107.6–320.7	52.5–152.5	157.5–675.0	2.0–36.0	64.5–185.0	7.5–33.5	8–150

*The data is expressed as mean and standard deviation (Mean ± SD) and 95% confidence intervals (95% CI) or median and interquartile ranges (IQR).

†The number of races per week represents in season figures while hours worked represents yard and riding work completed independent of racing commitments. The hours worked per week represents riding horses, mucking out stables and yard duties. The number of winners is positively skewed data and the median with interquartile range are presented.

‡$p \leq 0.05$ significantly different from all subgroups.

§$p \leq 0.05$ significantly different from professional flat group.

‖$p \leq 0.05$ significantly different from professional jump group.

¶$p \leq 0.05$ significantly different from apprentice group.

#$p \leq 0.05$ significantly different from conditional group.

Table 2
Physical activity levels of active jockeys (n = 66).*

Activity	Percentage participation	Frequency per wk, mean ± *SD* (95% CI)	sRPE, mean ± *SD* (95% CI)
1. Cardio	48.2% (n = 32)	3.4 ± 1.6 (2.9–3.9)	272.9 ± 134.8 (238.7–321.2)
2. Gym based training	10.6% (n = 7)	2.1 ± 1.2 (1.3–2.9)	315.4 ± 115.1 (240.2–390.6)
3. Golf	1.2% (n = 1)	1 ± 0 (1.0–1.0)	860 ± 28.2 (804.7–915.3)
4. Boxing	2.4% (n = 2)	3 ± 0 (3.0–3.0)	630 ± 127.3 (453.6–806.4)
5. Field based games	14.2% (n = 9)	1.3 ± 0.6 (0.9–1.7)	431.6 ± 76.4 (388.3–474.8)

*sRPE = Session rated perceived exertion (session intensity × session duration in minutes); CI, confidence interval.

Practice and Perceptions of Strength and Conditioning

Warm up. Forty-six jockeys (54.1%) reported that they performed a warm-up routine before racing. There was no significant difference between total flat (%) and total jump jockeys (%) (p = 0.530, [PHI] = 0.068) or between licensed subcategories (p = 0.129, [PHI] = 0.258). Participating jockeys reported they most commonly completed static stretching (42.4%), light aerobic activity (16.5%), dynamic stretching (8.2%), muscular activation exercises (7.1%), foam rolling (4.7%), and other (2.4%). The most frequent time reported for warm-up duration was 1–5 minutes (24.7%) with 8.7% of jockeys warming up for 20 minutes or greater.

Strength and Conditioning (S&C). Forty-two percent of jockeys that participated in S&C (n = 36) reported their most frequent type of S&C practice; cardio (52.8%), high-intensity interval training (HIIT) (33.3%), flexibility and mobility training (8.3%), and resistance training (5.6%). Of those that did not participate in S&C, reasons chosen included: "I don't have time" (42%), "I am too tired following riding work" (14%), "I am fit enough from riding work" (14%), "I don't enjoy it" (8%), "I don't want to gain weight" (8%), "I am not aware of S&C classes close to my work place" (6%), "I don't want to change current habits" (4%), "I don't have access to specialist S&C information" (4%). There was no significant association in S&C participation between total flat and total jump licenses (p = 0.085, [PHI] = 0.187) or between license subcategories (p = 0.237, [PHI] = 0.190). Table 3 represents the type of S&C class that would most appeal to jockeys in addition to the reason for that selection. Boxing classes were the most popular type of S&C class requested by jockeys with an improvement in riding fitness the most common justification for this class type.

Jockeys Perceptions of S&C and Sources of S&C Information. The sources jockeys used to obtain S&C information were described by the respondents and found to be varied and included; the Irish jockey pathway (15.3%), other jockeys (15.3%), S&C coach (14.1%), internet (9.4%), and other (5.7%), whereas 40% reported that they do not source information on S&C or physical preparation strategies. Seventy-six percent of the jockey population reported that they would like more information on S&C and physical preparation strategies. Jockeys preferred method to receive this information was; email (25.9%), a jockey-specific training app (24.7%), S&C classes (11.8%), online videos (5.9%), one to one consultation with an S&C coach (4.7%), social media (2.4%), and fact sheet (1.2%). Jockeys perceptions of the benefits of S&C can be seen in Table 4. Although a high percentage of jockeys reported knowledge surrounding the benefits of S&C for various parameters, uncertainty among the population existed around the benefit of S&C on weight management and the effect of S&C on the speed of movement.

Discussion

This is the first study to investigate the physical preparation strategies of jockeys. The knowledge and practice of S&C among jockeys were investigated to gain an understanding of the complex relationship between the athlete's preparation, weight restrictions, and the physical demands of the sport. The findings of this study highlight that S&C practices are highly variable and inconsistent. Both the sample size and 100% response rate (n = 85) was higher than other S&C-related studies; Rugby 83% (21), major league baseball 70% (11), rowing 54% (18), and American football 86% (12). The higher response rate may highlight the elite athletes', in this case professional jockeys, receptiveness to sharing training habits and knowledge or the potential benefit of face-to-face interaction when collecting data over electronic methods as used in the aforementioned studies.

The results of this study reveal that the license category of a jockey is directly related to the number of race wins. The license type is also related to the amount of opportunities that jockeys receive with flat jockeys receiving more races on average per week than any other jockey license category (16.3 ± 8.7). Data collection took part at the beginning of the flat season and end of the jump racing season, which may have influenced the number of races available to jockeys. Additional hours of work is not usual practice for professional athletes where a large emphasis is placed on balancing the stressors of the sport with appropriate recovery to maximize performance in addition to minimizing injury risk (22). Jockeys work a large amount of weekly hours (34 ± 14) in addition to completing weekly races (7 ± 6). It is not surprising that fatigue is prevalent among the jockey population (10) considering total riding commitments and ubiquitous difficultly with weight management reported by 55.3% of jockeys.

Jockeys are unique in comparison to other weight restricted sports in that they make weight daily (33). Boxers habitually lose weight by restricting fluid and food intake in the week leading to competition (19) and this was also more common than exercise for rapid weight loss with jockeys (8,33). Sixty-seven percent of jockeys reported that they must rapidly lose weight at least once a month. Exercise alone is used by only 29.4% of jockeys to achieve their required weight which is lower than previous research reported at 48% (8). Jockeys also use poor dietary habits with the consumption of convenience food quite common (10). In conjunction with low participation rates in additional physical activity outside of riding, it is not surprising that jockeys exhibit higher body fat measurements than other weight-restricted sports (9).

Approximately a quarter of jockeys (22.4%) reported no physical activity outside of riding-related activity. Although riding work is physically demanding (23) and jockeys work a large amount of hours, riding work does not match the

Table 3

Jockeys preferences for future S&C class types.*

S&C class type	Resistance training classes	Cardio based classes	Boxing classes	HIIT	Flexibility training	Injury prevention classes	Other	Total	Percentage %
Rationale for choice									
I enjoy it	0	3	2	1	0	0	0	6	7.0
It would be fun	1	1	10	0	0	0	1	13	15.3
Increase core strength	2	1	1	0	0	0	0	4	4.7
Improve riding fitness	0	7	11	8	0	0	0	26	30.6
Helps weight management	0	6	2	2	0	0	0	10	11.8
Increase overall strength	5	0	0	1	0	0	0	6	7.0
To prolong riding career	0	0	0	0	0	1	0	1	1.2
To improve riding performance	2	1	0	1	7	1	0	12	14.1
Prevent injuries	0	0	0	0	0	5	0	5	5.9
Improves overall well being	1	1	0	0	0	0	0	2	2.4
Total	11	20	26	13	7	7	1	85	
Percentage %	12.9	23.6	30.6	15.3	8.2	8.2	1.2		100%

*HIIT = high-intensity interval training.

physiological demands of race riding and thus does not expose jockeys to the intensity of race riding. Of those that participate in physical activity outside of riding, cardio activity was the most popular and although this is used as a useful weight-making tool, HIIT may expose the jockey to exercise similar to the intensity of race riding. To quantity additional activity, acute arbitrary sRPE units were calculated. Although this is the first time exercise has been quantified in horse racing, sRPE has been validated as a measure of global internal training load (25). Cardio exhibited the lowest sRPE, and this may be due to the low-intensity nature of the cardio activity. Acute load has been previously reported using arbitrary sRPE units in professional team games (5,24,25); however, normative data in weight-restricted sports are absent. Although these sports quantified physical training practice, only a limited number of jockeys partook in additional physical activity. Although gym based training, golf, boxing and field based games were reported only boxing reached comparable levels with training in team sport (>1750 arbitrary units) (25). The low number of subjects ($n = 2$) that reported boxing activity in this study does not allow for translational comparisons.

Research has shown that an adequate warm up can provide positive performance increments in both aerobic and anaerobic events with little evidence of detrimental effects (17). The elite jockeys in this study reported that just over half the athlete population warm up before racing (54.1%) with static stretching the most commonly used warm-up practice. Although further research is required on individual components of a warm up, it is understood that static stretching may not be the optimal preparation strategy for events which require maximal exertion due to negative decrements in power (27,35).

S&C practices have been widely documented in elite athletes; however, no previous study has examined the physical preparation of jockeys in this regard. It is unsurprising that cardio is completed by over 50% of jockeys with its prominence as a weight-making strategy also portrayed from the compiled data. Resistance training was the least commonly reported S&C modality used. This is in contrast with sports such as rowing, American football, Rugby union, and swimming where resistance training is consistently practiced and the specifics of programming are also detailed (6). Resistance training is known to have positive effects on performance in addition to health benefits through the maintenance and prevention of osteoporosis and sarcopenia (34). With jump jockeys in particular exposed to regular falls (50.9/1,000 rides) (15) in addition to the prevalence of osteopenia among the jockey population (31), resistance training must be advocated to all jockey licenses. Jockey's perceptions of the benefits of S&C and their most common sources of S&C information were reported. Of note is that 76% of jockeys reported interest in receiving further S&C information. Practitioners such as the Irish Jockey Pathway, a suite of professional performance services and other related international organizations should consider that email, a jockey-specific training application and

Table 4

S&C perceptions among jockeys.

Statement	I agree (%)	I neither agree or disagree (%)	I disagree (%)
S&C can improve your riding performance	88.2	10.6	1.2
S&C can reduce the risk of injury	84.7	0	15.3
S&C can slow your movement down	9.4	29.4	61.2
S&C can help you manage your riding weight	77.6	12.9	9.4
S&C can negatively affect your riding weight	8.2	38.8	52.9
S&C can improve your bone health	70.6	27.1	2.4
S&C can improve your balance and coordination	88.2	0	11.8
S&C can improve your general and specific endurance	94.1	2.4	3.5
S&C can improve your general and specific strength	91.8	4.7	3.5

S&C classes were the 3 most requested means to receive S&C-related information.

Practical Applications

This study provides a comprehensive insight into the physical preparation strategies typically used by professional jockeys. The data and information presented in the study in relation to weight-making strategies illustrates the need for both specific individualized exercise and dietary interventions within this population. It is understood that jockeys do not partake in physical activity which mimics the repeated high-intensity demands of racing. High-intensity interval training may be a useful training modality in bridging the gap between the physiological demands of riding work and racing. Furthermore, a detailed analysis of the specific physiological demands of both flat and jump racing is required to inform both jockeys and coaches in the implementation of optimal training practices. S&C coaches can use the data reported in this study to inform current and future S&C practices in addition to how best deliver S&C information to jockeys. Future questionnaires should look at the specific breakdown of S&C programs for jockeys in relation to exercise type and prescribed load.

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Appendix I. Journal Article: Physiological demands of professional flat and jump horse racing

Kiely, M., Warrington, G., McGoldrick, A., Pugh, J & Cullen, S. (2020). Physiological demands of professional flat and jump horse racing. *Journal of strength and conditioning research*.

Original Research

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Physiological Demands of Professional Flat and Jump Horse Racing

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Abstract

Kiely, M, Warrington, GD, McGoldrick, A, Pugh, J, and Cullen, S. Physiological demands of professional flat and jump horse racing. *J Strength Cond Res* XX(X): 000–000, 2020—No information is currently available on the effect of race distance on the physiological demands of jockeys. This study aimed to quantify the respective demands of short and long flat and jump race distances. Twenty professional jockeys (10 flat and 10 jump) participated in the study. The subjects initially performed a graded incremental exercise test to volitional exhaustion on a treadmill to determine the peak heart rate (HR) and blood lactate concentrations. Two competitive races (short and long) were then monitored on 2 separate occasions for each jockey type to obtain hydration, HR, blood lactate concentration, and rating of perceived exertion data. Mean distances for the 4 races were: 1,247.2 ± 184.7 m (short flat race), 2,313.4 ± 142.2 m (long flat race), 3,480.2 ± 355.3 m (short jump race), and 4,546.4 ± 194.3 m (long jump race). The mean HR for the long flat race was 151 ± 19 b·min^{-1} (79 ± 11% of HR_{peak}), which was significantly lower than all other race distances (p = 0.000, effect size [ES] = 0.469). A longer jump race resulted in a significantly higher reported rate of perceived exertion (RPE) (14 ± 2.8) than the short jump race (11.0 ± 1.5) (p = 0.009, ES = 0.271), whereas no significant difference was revealed between peak HR responses or blood lactate concentrations when comparing other race distances (p < 0.05). The finding of this study supports previous limited research, which suggests that horse racing is a high-intensity sport, whereas RPE and mean HR fluctuate according to the race distance.

Key Words: jockeys, physiology, physical demands, elite sport

Introduction

Horse racing is one of the oldest organized sports, yet there is a dearth of scientific research and application for jockeys. Horse racing is divided into 2 distinct categories: flat and jump racing. Traveling at speeds of up to 65 km/h, flat racing has no obstacles and takes place on a shorter course distance (1,000–3,200 m). Jump racing encompasses maneuvering a thoroughbred race horse weighing up to 500 kg over obstacles with distances ranging from 3,200–7,200 m. Jockeys frequently ride over a range of course distances within their discipline. Flat racing jockeys are required to weigh between 52.7 and 64 kg, whereas jump racing jockeys are required to weigh between 62 and 76 kg. These weights are inclusive of the horse saddle and full riding gear (4,6). Although maintaining the stipulated chronic low body mass, a sufficient level of conditioning is required to ride several races per day, for multiple days per week, with no established off season (4).

Individual athletes in sports such as running, cycling, and equine commonly differentiate between events within the sport and the relative physiological demands that the athlete is exposed to (7,21,22). Despite the popularity of horse racing, few studies have investigated the physiological demands of racing, whereas no study has evaluated the demands placed on jockeys relative to the race distance. Physiological demands can represent internal values that measure the biological status or exercise intensity with parameters of heart rate (HR), blood biomarkers, and ratings of perceived exertion commonly examined (13). To optimize jockey performance, researchers endeavor to provide information to strength and conditioning coaches and support staff in relation to the specific demands of both flat and jump racing in addition to specific distance-related measurements of intensity. Across sports, such information is deemed valuable to facilitate optimal training load and competition preparation (8). Furthermore, it may be argued that for jockeys of equal skill, fitness may enhance performance because it is evident in a multitude of sporting codes (1,12,24).

Horse racing has been previously described as a high-intensity sport requiring maximal efforts (4,17,26). Jockeys will typically maintain a position of forward propulsion, racing with the center of mass acting through the jockey's foot while balanced on a thin strip of metal known as the stirrup. An increase in effort with high-intensity activity is required in the final stages of a race (27). From an initial quasi-isometric squat position, jockeys will lower their center of gravity adopting a position of increased flexion at the knee and hip. At this stage, jockeys aim to minimize the movement of the lower body, squeezing the horse firmly with the inside of the lower leg, to encourage increased forward momentum. To lengthen the horse's stride, jockeys will then use their shoulders and arms to push out the horse vigorously at the neck with up to 2.5 pushes per second (27). Maintaining balance and rhythm throughout each action in alignment with the horse's movement is imperative.

Time and distance ranges have been reported in the literature for jump and flat racing, respectively (4,26); however, the mean

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time for specific race distances has not been previously described in either race types nor have they been compared. Only 2 studies have previously investigated the demands of flat racing with both studies denoting a high peak HR of 189 ± 5 b·min^{-1} (4) and 186 ± 14 b·min^{-1}, respectively (17). The mean HR for flat racing has been previously reported at 180 ± 6 b·min^{-1} (4) and 167 ± 12 b·min^{-1} (17). As the latter study included 30 seconds before and after race in the analysis, it is probable that the mean HR was underestimated. Neither study provided information on blood lactate concentration responses, indicating the necessity of this research to compare events. The peak HR has been reported in jump racing as 184 b·min^{-1} with a mean range of 136–188 b·min^{-1}, whereas peak lactate values were reported at 7.1 mmol·L^{-1} confirming high physiological demands (26).

Although the physiological demands of race riding are high, the specificity of preparation strategies needs to be improved. Riding out, a daily work activity for jockeys involves taking the horse through walking, trotting, and cantering. The physiological demands of these gaits do not meet those of the demands the same athletes face in competition (15). Previous research has found that only 42% of jockeys participate in strength and conditioning practice (14); therefore, further sport-specific training which includes relative competition demands is warranted among the jockey athlete population. With great disparity between race distances and duration jockeys compete over, a greater understanding of relative physiological responses will assist in the development of specific race-based conditioning programs. The aim of the study is therefore to profile and compare the physiological demands of short and long race distances in flat and jump racing about HR, blood lactate concentration, perceived exertion, and hydration status.

Methods

Experimental Approach to the Problem

A testing protocol was devised to explore the physiological demands of professional jockeys. The research was broken into 2 stages consisting of an initial maximal treadmill test to obtain peak physiological data and the subsequent physiological monitoring of jockeys during competitive professional racing. The research was framed with a research question rather than a prominent hypothesis. Previous approval for the study was granted by the Irish Horseracing Regulatory Board, the regulatory authority for Irish horse racing.

Subjects

Twenty professionally licensed jockeys participated in the study. The subjects comprised 10 flat racing jockeys and 10 jump racing jockeys. Both flat and jump racing jockeys were tested at separate times during their respective in-season. Participation in the study was voluntary with all jockeys receiving information on the risks and benefits of participation before providing informed consent. The study was approved by the Waterford Institute of Technology Research Ethics Committee in the spirit of the Helsinki Declaration. Informed consent documents were signed and gathered for all subjects before commencement of testing. The funding organization had no role in the collection of data, their analysis, and their interpretation.

Procedures

Anthropometrics and Physiological Baseline Testing. The height was measured to the nearest centimeter (cm) using a stadiometer (Seca, Leicester Height Measure). The body mass was recorded in minimal clothing using a portable digital scale (Salter, Germany). Subjects were then asked to remain in a seated position for 5 minutes to obtain the resting blood lactate concentration (Lactate Pro, Akray, Kyoto-shi Kyoto-fu, Japan) from the earlobe and HR values (Polar H10 Electro, Kempele Finland). Subjects completed a treadmill test to volitional exhaustion on a nonracing day to determine peak HR values and blood lactate concentration values.

The incremental running test to volitional exhaustion was completed on a motorized treadmill (Taurus, Germany) with an incline of 1°. After a 5-minute warm-up on the treadmill at 8 km·hr^{-1}, a ramp protocol was used with an initial velocity increase of 1 km·hr^{-1} each minute. A rate of perceived exertion (RPE) score (6–20) was collected at each speed and gradient change (2). When the subject reported an RPE of 14 arbitrary units, velocity was maintained, and the gradient was thereafter increased by 1° each minute. The test was ceased once volitional exhaustion was achieved.

Maximal tests necessitate subjects to exercise to the point of volitional exhaustion (19). The test was considered a maximal test if 3 of the following ACSM criteria were met: (a) A final HR of within 5 beats of the age-predicted maximum (220 b·min^{-1}—age); (b) an RPE of 19 or greater to establish volitional exhaustion; and (c) a final blood lactate concentration value of 8 mmol·L^{-1} or more. These criteria were met with each subject. The peak HR was noted at the completion of the test from the "Polar Beat" application. The blood lactate concentration was measured at minutes 1, 3, 5, 7, and 9 after tests. When a decline in the lactate concentration was noted, the previous score was taken as the peak concentration value.

Race Data Collection. Race data for flat racing and jump racing jockeys were collected within 4 weeks of the laboratory tests at various racecourses over short and long course distances on a turf track. Mean distances for the 4 races were 1,247.2 ± 184.7 m (short flat race), 2,313.4 ± 142.2 m (long flat race), 3,480.2 ± 355.3 m (short jump race), and 4,546.4 ± 194.3 m (long jump race). Air temperature and humidity were reported at the start of each race from the national weather forecasting application (Met Eireann, Dublin, Ireland). After the completion of a pretest medical screening form, urine specific gravity (USG) was measured using an RS pro refractometer (RS PRO, Dublin, Ireland). Urine specific gravity values of <1.020 were considered indicative of euhydration and values ≥1.020 indicative of hypohydration (18).

The prerace blood lactate concentration was taken within 15 minutes before the race starts. The Polar H10 monitor was also fitted at this time to gather in race HR data. A minimum of 60 minutes of no riding was required before each race to ensure blood lactate concentrations were at resting levels (≤2 mmol·L^{-1}). If blood lactate concentration levels were above resting values, the race was not monitored for the jockey.

After the race, the jockeys' finishing position was recorded. The raw HR data were automatically downloaded to the Polar Beat application. It was later time stamped and synchronized with the race start time to retrieve mean and peak HR values. Blood lactate concentration and RPE values were recorded between 5 and 7 minutes after race on return of the jockey to the weighing room.

Table 1
Mean ± *SD* Anthropometrics, peak heart rate, and peak blood lactate concentrations.

Variables	Jump ($n = 10$), mean ± *SD*	Flat ($n = 10$), mean ± *SD*
Age (y)	25 ± 4	26 ± 6
Height (cm)	174.0 ± 5.0	168.0 ± 5.0
Body mass (kg)	65.0 ± 3.3	57.6 ± 2.4
Peak heart rate (b·min^{-1})	194.0 ± 9.0	192.0 ± 8.0
Peak blood lactate concentration (mmol·L^{-1})	11.1 ± 2.7	10.0 ± 2.5

Statistical Analyses

Data were analyzed using SPSS (Statistical Package for the Social Sciences V22.0, SPSS Inc, Chicago, IL). Data were assessed for normality using a Shapiro-Wilk test, whereas descriptive data were presented as mean and standard deviation (mean ± *SD*) with a 95% confidence interval. To investigate whether any differences existed between group means for the 4 race types (short flat race, long flat race, short jump race, and long jump race), a 1-way analysis of variance was administered. A Tukey HSD post hoc comparison was applied to determine the location of the differences between the 4 groups. The statistical significance was set at $p \le 0.05$ level. Effect sizes (ES) for between group differences were calculated using eta-squared with 0.2 considered a "small" ES, 0.5 a "medium" ES, and 0.8 a "large" ES (3).

Results

Anthropometrics

The mean anthropometric data for both flat and jump racing jockeys are reported in Table 1. The mean values for peak HR and peak lactate concentration are also reported for both jockey groups from the volitional exhaustion test.

Climatic Conditions and Hydration Levels

The mean temperature (°C), humidity (%), and USG (g·mL^{-1}) for each race type are reported in Table 2. There was no significant difference between temperature or humidity when comparing the short and long flat races or the short and long jump races. However, the temperature and humidity were significantly higher during both flat races in comparison with the jump data collection period ($p = 0.000$and ES = 0.735).

Race Characteristics and Physiological Responses

The race characteristics and physiological responses can be seen in Table 3. In jump racing, a longer race distance resulted in a significantly higher reported RPE than the short race ($p = 0.009$, ES = 0.271), whereas no significant difference was revealed between peak HR responses or blood lactate concentrations when comparing other race distances. The mean HR in the long flat race (151 ± 19 b·min^{-1}) was significantly lower than the mean HR reported in all other race distances ($p = 0.000$, ES = 0.469). No significant difference was noted between the flat race distances when comparing other race distances for peak HR, RPE, or blood lactate concentrations ($p < 0.05$).

Discussion

Although only 3 studies have previously investigated the physiological demands of horse racing, this study is the first to evaluate the demands of short and long race distances for either flat or jump racing. Our current study has revealed differences in both HR and RPE between various race distances. It is envisaged, given the dearth of current research, that these quantitative data sets will aid coaches and sports medical staff in both the conditioning and rehabilitation of jockeys to meet racing demands.

In alignment with previous research (4,17,26), peak HR measurements reported in this study indicate that a jockey has regular exposure to high-intensity activity while racing. Mean HR and peak HR compare closely to the physiological strain experienced by both individual and team sport athletes. In competition, elite downhill mountain bike cyclists have exhibited mean and peak HRs of 183 ± 6 b·min^{-1} and 194 ± 8 b·min^{-1} (25). In team sport, peak HR in both Gaelic football (201 ± 16 b·min^{-1}) and soccer (193 ± 3.3 b·min^{-1}) reports similar peak HR values as experienced by jockeys (20,23). The recording of mean and peak HR provides a useful index of overall physiological strain during competitive races with the polar H10 monitor providing a gold standard device for assessments during intense activities (10).

The peak blood lactate concentration reported across 3 race types (long jump race, short flat race, and long flat race) seemed maximal in the nature (≥8 mmol·L^{-1}), whereas the mean values of all races were higher than previously reported racing values (26). With blood lactate concentrations reporting higher after racing when compared with preracing resting values (≤2 mmol·L^{-1}), it may be assumed that energy is mainly derived from anaerobic lactic and aerobic pathways (25). The blood lactate concentration is frequently used as an indicator of energy production from anaerobic glycolytic processes. Although no blood lactate accumulation data are available from jockeys riding out,

Table 2
Mean (±*SD*) temperature, humidity, and urine specific gravity for each race.*

Variables	Jump racing ($n = 10$), mean ± *SD*		Flat racing($n = 10$), mean ± *SD*	
	Short race	Long race	Short race	Long race
Temperature(°C)	9.8 ± 3.5‖¶	10.3 ± 3.0‖¶	18.9 ± 1.4‡§	17.6 ± 1.8‡§
Humidity (%)	77.0 ± 5.1‖¶	77.2 ± 5.6‖¶	63.4 ± 7.4‡§	60.7 ± 7.7‡§
USG (g·mL^{-1})	1.023 ± 0.005	1.020 ± 0.008	1.018 ± 0.010	1.018 ± 0.010

*USG = urine specific gravity.
‡$p < 0.05$ significantly different from the short jump race group.
§$p < 0.05$ significantly different from the long jump race group.
‖$p < 0.05$ significantly different from the short flat race group.
¶$p < 0.05$ significantly different from the long flat race group.

Table 3

Mean (±*SD*) race characteristics and physiological responses of jockeys.*

	Jump racing (n = 10), mean ± *SD*		Flat racing(n = 10), mean ± *SD*	
Variables	**Short race**	**Long race**	**Short race**	**Long race**
Distance (m)	3,480.2 ± 355.3	4,546.4 ± 194.3	1,247.2 ± 184.7	2,313.4 ± 142.2
Time (s)	263 ± 33	355 ± 18	78 ± 12.2	157 ± 10.4
Finishing position	5 ± 3	5 ± 3.	4 ± 2	5 ± 2
Mean HR ($b \cdot min^{-1}$)	181.0 ± 8.0¶	182.0 ± 9.0¶	172.0 ± 15.0¶	151.0 ± 19.0†
	(93 ± 3% of lab HR_{peak})	(94 ± 3% of lab HR_{peak})	(89 ± 6% of lab HR_{peak})	(79 ± 11% of lab HR_{peak})
Peak HR ($b \cdot min^{-1}$)	192.0 ± 6	195.0 ± 9.0	190.0 ± 12.0	186.0 ± 14.0
	(99 ± 3% of lab HR_{peak})	(101 ± 3% of lab HR_{peak})	(99 ± 4% of lab HR_{peak})	(97 ± 4% of lab HR_{peak})
RPE	11.0 ± 1.5‡	14.0 ± 2.8§	13.0 ± 2.1	14.0 ± 1.3
Peak Bla ($mmol \cdot L^{-1}$)	7.4 ± 2.2	9.6 ± 3.2	8.6 ± 2.5	8.2 ± 1.5
	(50 ± 2% of lab $[La]_{peak}$)	(92 ± 40% of lab $[La]_{peak}$)	(86 ± 14% of lab $[La]_{peak}$)	(82 ± 16% of lab $[La]_{peak}$)

*HR = heart rate; RPE = rate of perceived exertion; Bla = blood lactate concentration.
†Significantly different from all subgroups.
‡$p < 0.05$ significantly different from the short jump race group.
§$p < 0.05$ significantly different from the long jump race group.
¶$p < 0.05$ significantly different from the long flat race group.

practitioners should ensure jockeys experience the anaerobic activity to enhance lactate clearance (9).

Jump racing jockeys reported a significantly higher RPE in the long race (14.0 ± 2.8) when comparing the 2 jump distances; however, there was no significant difference for HR or blood lactate concentrations between the short and long jump races. The increased perceived exertion may be linked to the longer duration of the event (355 ± 18 seconds). It is understood that RPE is a proven methodological approach in monitoring training intensity with an intraclass correlation coefficient of 0.88 when investigating high-, moderate-, and low-intensity sessions (5,11). With jockeys reporting higher exertion levels over longer distance races, RPE may provide a valuable metric to replicate racing intensity with gym-based exercises.

Although no significant difference was noted in the hydration status between the 4 races, flat racing jockeys reported to be in a state of hypohydration (USG ≥1.020). Although no association was evident with the HR or RPE in this study, body mass loss through dehydration can elevate HR and perceived exertion among athletes (16). There was a significant difference between temperature and humidity values when comparing the flat and jump racing seasons. The varied weather conditions are aligned with expected seasonal differences between the respective flat and jump racing seasons. Although significantly higher humidity and temperature occurred during the flat data collection period, the mean HR was lower for both flat race distances. An increase in air temperature is frequently associated with homeostatic disturbances. Adequate hydration strategies during competition are essential to minimize changes to homeostasis (24).

There are several limitations to the current study. The sample size was small, so climatic conditions, ground conditions, the use of different horses, and the fitness of the subjects may have some influence on the findings. Although hydration levels were reported with no significant difference between races, energy intake was not accounted for with each jockey. In addition, the HR reported may be elevated beyond the normal HR-$\dot{V}O_2$ relationship due to prolonged isometric contractions during riding, climatic conditions, or emotional stress. Governing authorities in horse racing do not permit the measurement of $\dot{V}O_2$ during competition. In addition to relative HR and blood lactate concentration values reported in this study, future studies should provide a relative level of fitness for each jockey group to investigate whether there is an association between jockey fitness and the physiological responses during racing.

In conclusion, this research specifies that both flat and jump racing jockeys experience great physiological demands during racing. These high demands in addition to the relevant danger associated with the weight category sport suggest horse racing is far more demanding than is currently recognized. Future studies may look at developing a relevant physical testing protocol, which would aid an investigation of association between the fitness level of individual jockeys and the physiological demands of racing.

Practical Applications

This study provides evidence that horse racing is a high-intensity sport. Because jockeys do not experience high physiological strain while riding out, they should therefore be encouraged to perform periods of high-intensity bouts, which mimic and exceed the HR demand and the blood lactate concentration experienced in racing. These high-intensity activities should focus on the body positions and movements that will be used in the subsequent performance. Particular attention should be given to prolonged isometric squatting positions with flexion of the hip and knee and culminating short high-intensity pushing activities. The current findings can provide a reference point for coaches to address the physiological development of the jockey with relative race duration and intensity ranges provided for flat and jump racing to assist in the achievement of peak athletic performance.

Acknowledgments

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Appendix J. Journal Article: Physiological demands of daily riding gaits in jockeys.

Kiely, M., Warrington, G., McGoldrick, A., O'loughlin, G., & Cullen, S. (2019). Physiological demands of daily riding gaits in jockeys. *The Journal of sports medicine and physical fitness*, *59*(3), 394-398.

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ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Physiological demands of daily riding gaits in jockeys

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ABSTRACT

BACKGROUND: Jockeys should maintain a high level of physical fitness to meet the physical demands of horse racing. The aim of this study was to determine the physiological requirements of the riding gaits used regularly in training.

METHODS: Eleven trainee jockeys performed a maximal incremental Wattbike cycle ergometer test. Mean absolute and relative oxygen uptake (VO_2) and heart rate (HR) were recorded for the steady-state period during a walk, trot and canter. Energy expenditure (EE) and associated metabolic equivalent (MET) were also estimated.

RESULTS: During a walk, trot and canter, relative mean VO_2 corresponded to 15±4%, 38±6%, 47±9% of VO_{2peak} and mean HR corresponded to 48±6%, 60±6%, 71±7% of HR_{peak} respectively. Mean VO_2 and mean HR were significantly different amongst gaits; P≤0.001. Walking required the lowest estimated EE of 2.25±0.6 kcal min^{-1} (P≤0.001; 2.4 METs;) and it was significantly lower than trotting at 5.72±1.0 kcal min^{-1} (P≤0.001; 6.2 METs) and cantering at 7.10±1.8 kcal min^{-1} (P≤0.001; 7.7 METs).

CONCLUSIONS: These riding activities are associated with relatively low physiological demand and alternate modes of exercise are recommended for trainee jockeys to ensure the demands of racing are met. Future research should investigate the physical training, both riding-specific and general conditioning, jockeys perform in preparation for racing.

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KEY WORDS: Horses - Exercise - Energy metabolism.

Professional horseracing is a physically demanding sport[1-3] with professional jockeys partaking in both flat (1-4 km) and national hunt racing races (3.2-7.2 km). It has been suggested that jockeys are required to be aerobically and anaerobically fit in order to perform optimally.[1] Jockeys may be asked to compete several times a day, up to 7 days a week, with no specific off-season.[4, 5] In preparing jockeys to meet the demands of racing, it can be expected that jockeys experience faster recovery rates, improved decision making and a reduction in the likelihood of falls.[6-8]

To be successful in a race, it has been suggested that jockeys must exercise close to their physiological capacity.[2] Trowbridge *et al.*[2] reported a peak heart rate (HR) of 184 beats·min^{-1} (range, 162-198 beats·min^{-1}) in jockeys competing in National Hunt Races and mean HR above 80% of the measured maximal HR for the duration of the races. Similarly, Cullen *et al.*[1] also reported high average HR in both simulated and competitive flat racing indicating the intense demands of the sport. Peak VO_2 among apprentice jockeys in a simulated flat race was reported as 42.74±5.6 mL·kg^{-1}·min^{-1} (75±11% of VO_{2peak}).[1] In addition a simulated 3200 m national hunt race is estimated to expend 43.02±7.17 kcal.min^{-1} of energy[3] while total energy expenditure during a simulated flat race (1400 m) was estimated to be 22.1±4.49 kcal.min^{-1} [1].

A typical working day for a jockey can include riding out, sport specific "work" (fast paced riding) and "schooling" (specific practice for races) while additional hours includes "mucking out," brushing horses and carrying buckets of feed and water.[3] Many hours are often spent in the typical riding gaits of a walk, trot and canter yet the physiological demands of these common gaits engaged in by jockeys remain unknown. Therefore, the aim of this study was to determine the physiological demands and estimated energy requirements of a walk, trot and canter.

Materials and methods

Subjects

Eleven male trainee jockeys were recruited through the Racing Academy and Centre of Education (RACE) training school for young jockeys in Ireland. Trainee jockeys were used to allow ease of data collection in a controlled environment. Written informed consent was obtained before commencement of data collection while parental/guardian consent was gathered from those under 18 years of age. All participants were asked to abstain from alcohol and unusual strenuous physical activity in the 24 hours prior to data collection. All protocols were designed in line with the World Medical Assembly Declaration of Helsinki. The Dublin City University Research Ethics Committee, granted ethical approval for this research study.

Procedures

Anthropometric data was initially collected. Each participant then performed a maximal incremental test on a Wattbike cycle ergometer test (Wattbike Ltd, Nottingham, UK) and on a separate occasion, an outdoor riding trial involving three equine riding gaits of walk, trot and canter. Physiological function was assessed through measurement of respiratory metabolic measures and HR with the mean VO_2, HR and EE recorded in all tests.

Anthropometric measurements

Stature was assessed to the nearest centimeter (cm) using a stadiometer (Seca, Leicester Height Measure). Body mass was measured in minimal clothing using a portable digital weighing scales (Salter, Germany). For the measurements of body composition, a Harpenden skinfold callipers (Cambridge, Scientific Industries, UK) was used to measure double thickness subcutaneous adipose tissue at seven sites; biceps, triceps, subscapular, supraspinale, abdominal, mid-thigh and medial calf. Mean scores were reported from the right side of the body using a minimum of three repeated measures. Percentage body fat was then estimated using the sum of skinfold measurement method.[9] An experienced ISAK level practitioner took all measurements.

Maximal Incremental Test

Participants performed an incremental maximal cycle ergometer test to volitional exhaustion to determine peak HR (HR_{peak}) and peak VO_2 (VO_{2peak}). The test began with a warm up at 60 watts for 5 minutes followed by three-minute stages beginning at 60 watts and increasing by 25 watts until volitional exhaustion. Volitional exhaustion was determined when each participant reported a score of twenty using Borg's rating of perceived exertion (RPE) Scale.[10] The same investigator recorded all perceived exertion scores to ensure participants understood the testing protocol and reached maximal volitional exhaustion. HR was measured continuously throughout the test using the Polar HR monitor (Polar, Finland) while a portable gas analysis system (Cosmed K4b2, Italy) was used to measure VO_{2peak}.

Outdoor riding trial

Each participant completed an outdoor riding trial, which consisted of three gaits of walk, trot and canter which occurred in succession. A minimum of three minutes of mean physiological data were recorded, for each gait, via the Cosmed and HR monitor to estimate mean and peak VO_2 and HR. Data were reported in relation to the peak values ascertained during maximal testing. An estimate of velocity was reported during the steady state of each riding gait using a wrist worn Global positioning System (GPS) (Garmin Forerunner 405). EE was estimated using the Weir equation.[11] Data was recorded during the steady state period of each riding gait. This was to ensure the demands of one riding gait did not affect the accuracy of measurement of the following gait. Different training horses were used in RACE and while these were all proposed by training staff as having similar temperaments, this was not measured. The various riding gaits in the study were also assigned a MET value; light (< 3 METs), Moderate 3-6 METs, Vigorous (6-9 METs).[12]

Statistical analysis

Descriptive statistics with a Greenhouse-Geisser correction were calculated for each dependent variable for each task, and results were presented as mean±standard deviation (SD). Normality of data distribution was tested using the Shapiro Wilks test. A repeated measures ANOVA was administered to investigate any difference between the physiological measures reported for each riding gait. A pairwise comparison identified the location of the significant difference if present. The Bonferroni procedure was used to calculate the acceptable level of significance. Significance was accepted at $P \leq 0.05$.

TABLE I.—*Descriptive data for the trainee jockeys (N.=11).*

Age (yrs)	16±1
Stature (m)	1.67±0.01
Body mass (kg)	55.2±6.1
BMI kgm^{-2}	19.9±1.8
VO_{2peak} (mL·kg^{-1}·min^{-1})	54±3.3
HR_{peak} (beats min^{-1})	185±7.0

Data are presented as mean±SD.

TABLE II.—*Physiological data of riding gaits (N.=11).*

Physiological variable assessed	Walk	Trot	Canter
Mean velocity (km·h^{-1})	4.6±0.7	7.3±1.2	28.4±1.0
Mean VO_2 (mL·kg^{-1}·min^{-1})	8.3±2.1	21.7±3.3[a]	26.8±5.0[a, b]
Mean HR (beats min^{-1})	91±9	115±11[a]	135±15[a, b]

Data are presented as mean±SD. Mean VO_2 and Mean HR were significantly different amongst gaits; $P\leq 0.001$.
[a]Significantly different than walk gait; [b]significantly different than trot gait.

Results

Physiological data

Mean anthropometric and peak physiological data for trainee jockeys are presented in Table I.

Mean velocity, VO_2 and HR recorded for the steady-state period in each riding gait are presented in Table II. A progressive significant increase in VO_2 and HR was observed from walk to trot to canter.

Relative mean VO_2 throughout each gait are summarized in Figure 1. A progressive significant increase in VO_2 was observed between walk to trot to canter (walk; 15±4% VO_{2peak}, trot: 38±6% VO_{2peak}, canter: 45±9% VO_{2peak}; $P\leq 0.001$). A Greenhouse-Geisser correction determined that mean VO_2 differed significantly between the riding gaits; walk to trot, trot to canter and walk to canter ($F(1.599, 15.998)=109.975$, $P<0.001$, $\eta^2=0.917$).

Relative mean HR throughout each gait are summarized in Figure 2. A progressive significant increase was found between riding gaits (walk: 48±6% HR_{peak}, walk: 60±6% HR_{peak}, canter: 71±7% HR_{peak}; $P\leq 0.001$). A Greenhouse-Geisser correction determined that mean HR differed significantly between riding gaits; walk to trot, trot to canter and walk to canter ($F[1.443, 17.322]=65.197$, $P<0.001$, $\eta^2=0.845$).

Energy expenditure

Walking required the lowest estimated EE with a value of 2.15±.47 kcal.min^{-1} (2.4 METs; light intensity activity) and it was significantly lower than trotting at 5.72±1.0 kcal.min^{-1} ($P\leq 0.001$; 6.2 METs; vigorous activity), and cantering at 7.10±1.8 kcal.min^{-1} ($P\leq 0.001$; 7.7 METs; vigorous activity). Estimated EE was also significantly different between the riding gaits of trot and canter ($F[1.405, 14.052]=86.863$, $P<0.001$, $\eta^2=0.897$).

Discussion

The aim of the study was to determine the physiological demands and energy requirements of common riding gaits used in training of horse racing jockeys. This is the first study of its kind to investigate the physiological demands of riding gaits typically performed during daily riding in jockeys. Results from this study show that there is a con-

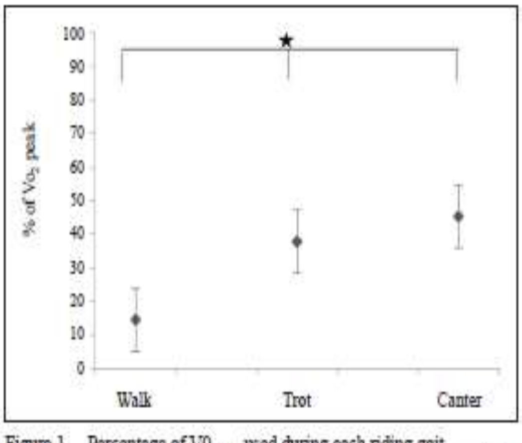

Figure 1.—Percentage of $V0_{2peak}$ used during each riding gait.
Data presented as mean±SD was significantly different among riding gaits. The star symbol is $P\leq 0.001$.

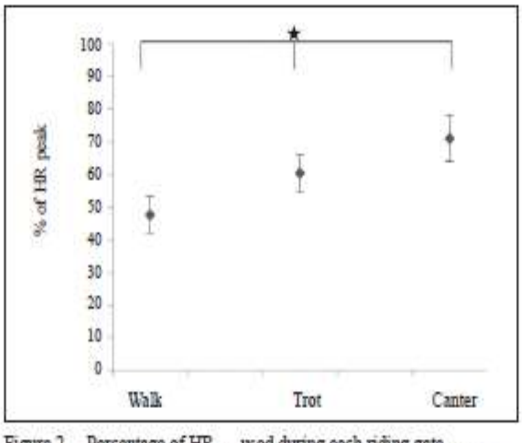

Figure 2.—Percentage of HR_{peak} used during each riding gate.
Data presented as mean±SD was found to be significantly different amongst gaits. The star symbol is $P\leq 0.001$.

siderable and progressive physiological load placed on the rider during each gait phase from a walk to trot to canter, however they are lower than the demands placed on riders in a racing environment as previously reported by Cullen *et al.*[1] and Trowbridge *et al.*[2] The results from this study indicate the riding alone is insufficient to prepare jockeys to meet the demands of racing. Additional exercise modes that match or exceed the intensity and demands placed on jockeys while racing are encouraged.

In the current study of 11 trainee jockeys mean VO_2 and HR were shown to be lower than previously found with recreational riders, defined by Devienne *et al.*[13] on subjects who rode for leisure on average 7 hours per week. An increase in VO_2 consumption was also observed during each gait trial in Dressage.[13] Similar to Devienne *et al.*[13] energy demand in this study progressed as riding pace increased through walk, trot and canter in trainee jockeys. Greater riding experience and the amount of riding undertaken per week may aid in the explanation in the difference between the results found in this study and the higher physiological responses recorded with recreational riders. It is thought that frequent exercise induces adaptation of the autonomic nervous system.[14] Increased riding exposure may result in positive physiological adaptation among the trainee group and thus lower physiological response through improved riding economy.

The MET values established during this research are coherent with those values previously reported for horse racing in the compendium of physical activities; namely walking at 3.8 METs, trotting at 5.8 METs and canter at 7.3 METS.[12] In the present study walking was classified as light intensity exercise at 2.4 METs with this intensity comparable to mild stretching. Trotting and cantering were recorded at 6.2 and 7.7 METs respectively deeming them a vigorous intensity exercise. In a sporting context, at the reported levels, trotting is comparable to tennis doubles or leisurely cycling at 16-19 $km \cdot h^{-1}$ according to the compendium, while cantering is equivalent to singles tennis or leisurely cycling at 19-22 $km \cdot h^{-1}$.[13] Such riding gaits would be performed frequently for morning training in addition to cleaning, 'mucking out', grooming and other laborious tasks. The intensity of the reported MET values for walk, trot and canter, although deemed vigorous activity by the compendium of physical activity,[12] are lower than the equivalent MET intensity of reported peak $V0_2$ values in both national hunt and flat racing.[1, 2]

In relative terms, these repeated riding activities predispose jockeys to relatively low physiological stress compared to the peak physiological data collected. Research in competitive flat racing has reported greater values; peak HR reached 189±5 $beats \cdot min^{-1}$ [1] while in National Hunt racing peak heart was reported at 184 $beats \cdot min^{-1}$ (range 162-198 $beats \cdot min^{-1}$).[2] The findings of this research indicate that physical exertion through the typical riding gaits used in training does not meet race intensity of either Flat or National Hunt racing and thus does not provide an appropriate training stimulus. Although the majority of a race is performed in the "canter" position, daily riding does not require an "all out" physical effort in the final stages as described by Wilson *et al.*[3] where concentric and eccentric efforts are required at an elevated intensity to "push out" or speed up the horse. This study monitored morning riding, which included walk, trot and canter only, which is primarily used for the maintenance of a horse's fitness level. The findings of the research convey the importance of galloping and faster riding work to be included for a jockey's race preparation due to the absence of maximal exertion in the researched gaits.

It has previously been suggested that National Hunt jockeys with a higher VO_2 max than their riding counterparts may have reduced falls and thus reduced risk of injury.[8] Mean VO_2 reported in the present study during walk, trot and canter respectively (15±4% VO_{2peak}, 38±6% VO_{2peak}, 45±9% VO_{2peak}) were subordinate to the peak demands of Flat Racing reported by Cullen *et al.*[1] These findings may propose the use of alternate training strategies for jockeys as the training gaits do not meet the intensity of racing. As proposed by Cullen *et al.*,[1] high intensity interval training (HIIT) should be incorporated to meet the demands placed on jockeys in horseracing. The benefits of improving the fitness levels of jockeys include improving aerobic and anaerobic function, which may aid postural positioning[1] while also enhancing recovery between rides.[2, 13]

Limitations of the study

The present study has provided novel data; however, there are a number of limitations that exist which may aid future research; Although the horses used in this study were all of a similar lethargic temperament, horses that are lethargic need to be encouraged which requires a higher metabolic cost.[13] In addition the physical demands can be also dependent on the rider style,[13] while a relatively small sample size was recruited for this study due to limited availability of jockeys at RACE.

Conclusions

The results of this study provide a greater insight and understanding of the physical demands of walk, trot and canter for horse racing jockeys. Evidence from this research conveys a disparity between the demands of competitive racing and the demands placed on the jockey during the relevant training gaits. It is of great significance that an understanding of jockey training best practice is advanced to allow jockeys train for optimal performance while maintaining a low body mass. This can aid jockeys transition from traditional training strategies and adopt additional forms of training with higher physiological demands such as HIIT to optimise racing performance while improving aerobic and anaerobic fitness.[1]

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