Physiological demands of jockeys in relation to injury risk, performance, and career longevity

A thesis presented
in partial fulfilment of the requirements
for the degree of

Doctor of Philosophy

at

School of Veterinary Sciences

Massey University
Manawatu
Aotearoa, New Zealand

Kylie A. Legg

2022

i Abstract

Jockeys work at close to their physiological capacity during a race. However, despite the pivotal role of the jockey in the success of racing, there are limited data published on the physiological challenges of race riding and the influence of muscular fatigue on the jockeys during a race and over their careers. Until the sport-specific physiological demands of race riding are quantified, the development of evidence-based sport specific and potentially performance enhancing jockey training programmes cannot be realised. Successful training interventions require knowledge of the physiological demands and performance characteristics of the specific sport. Therefore, the aims of this thesis were to characterise the injury risk, performance and career longevity of jockeys in relation to their overall and specific, training and competition level physiological demands.

Using race-day records of 786 jockeys riding over 14 years (2005 – 2019) of Thoroughbred racing in New Zealand (n = 421,596 starts), descriptive statistics, uni- and multi- variable analyses and Kaplan Meier survival curves, it was determined that jockeys with higher competitive workloads performed better, had fewer falls and longer careers than those with lower competitive workloads. A nationwide online survey completed by 40% of the jockey population in New Zealand identified that the main form of exercise for jockeys was riding in training and racing. This indicated that jockeys with higher competitive workloads may have a greater degree of sport specific fitness from regular competitive riding that jockeys with lower workloads (or apprentice jockeys beginning their career) are unable to gain through simply riding track-work and trial rides.

The ride specific physiological demands, body displacements and muscle activities of jockeys were determined by instrumenting jockeys with heart rate (HR) monitors, global positioning system (GPS), accelerometers (body displacement) and electromyographic clothing (recording eight muscle groups: *quadriceps, hamstrings, gluteal, lower back, obliques, abdominal, trapezial* and *pectoral*) during a typical day at track-work, trials, and races. The physiological (aerobic) demands of riding increased from low during track-work, to moderate when riding trials, and near-maximal during race-riding. Race-riding jockeys adopted a lower crouched posture with greater *hamstring* activation than jockeys riding track-work or trials. These studies provide evidence that jockeys need more specificity in training for competitive race-riding. Future studies could use these data to model the optimum level of competition specific fitness for a jockey to maintain to both reduce injury risk and optimise performance, which would in turn, enhance the career longevity of jockeys.

ii Acknowledgements

I would like to thank the many people that have helped and encouraged me over the past three years and have made the experience so worthwhile. I would first like to thank my supervisors Professor Chris Rogers, Associate Professor Darryl Cochrane and Associate Professor Erica Gee. I am most grateful for their help, encouragement, brainstorming sessions, enthusiasm and editorial skills during the year. To Chris, thank you for your ideas, time, encouragement and interesting discussions which have introduced me to so much research in many areas and encourage me to look at the big picture. Darryl, thank you for putting up with my countless questions on sport science and methodology, as well as pointing me towards useful resources and the many hours spent on road trips. Erica, thanks for keeping me focussed and on track, whilst remembering to take time to enjoy the horses.

Without the help and collaboration of Nik Whitfield, Tony Russell and Ian Harman in organising and sorting suitable equipment for field data collection and help with many miscellaneous requests, this study would not have been possible. Their help and good humour were greatly appreciated and enhanced both the quality and success of this study.

A special thank you to Brooke Adams and Yin Chin for all the help and guidance with data collection and as sounding boards for ideas and data cleaning and editing, not to mention all the road trips (and cheese scones). Your positivity and enthusiasm for the project throughout was invaluable. Many thanks also to Laureline Guinnefollau, Meg Rogers and Michaela Gibson for their help as trial subjects and sharing their wisdom.

For their valuable help in preliminary editing and comments, technical engineering advice and as sounding boards for a myriad of questions, Professor Stephen Legg, Dr. John Saywer and Dr. Annæ Buchmann - their thoughts and comments were much appreciated.

Financial assistance from the Massey University Doctoral Scholarship and New Zealand Equine Trust was greatly appreciated. The author would like to acknowledge the role played by NZTR in facilitating this research to take place, in particular Amy Johnson, Sally Waters, Marty Burns and Sophie Hargreaves who helped to liase with and motivate the jockeys. In addition, special thanks go to each of the apprentice and professional jockeys who gave their willing and enthusiastic assistance to participate in this study.

Finally, a very special thank you to my family and friends for all their unfaltering support and encouragement throughout this journey. In particular, this thesis was made possible thanks to the steadfast support of my mother. My sanity was kept by spending time and many adventures with my herd mates – Mocha, Buzz, Indi, GT and Ara. I now look forward to applying applications from this study to further improve human and horse interaction in the future.

“Take wisdom from the wise - not everyone who rides a horse is a jockey.” - Arabic Proverb

iii Publications

The chapters reported in this thesis were completed during candidature and have been presented in the following communications. Permissions were granted from each of the corresponding journals to publish the outputs in this thesis.

Journal articles

Chapter 1

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Review of physical fitness, physiological demands and performance characteristics of jockeys. *Comparative Exercise Physiology*, 17(4): 319-329. doi:https://doi.org/10.3920/CEP200079

Chapter 2

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport*, 23: 1154-1160. doi:10.1016/j.jsams.2020.05.015

Chapter 3

Legg, K. A., Cochrane, D., Gee, E., & Rogers, C. (2020). The external workload of Thoroughbred horse racing jockeys. *Sustainability*, 12(18). doi:10.3390/su12187572

Chapter 4

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2020). Jockey career length and risk factors for loss from Thoroughbred race riding. *Sustainability*, 12(18). doi:10.3390/su12187443

Chapter 5

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Physical activities of jockeys during a working week. *Comparative Exercise Physiology*, 18(1): 75-83. doi:10.3920/cep210011

Chapter 6

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of “track-work” riding in apprentice jockeys. *International Journal of Sports Physiology and Performance*, 17(12):1698-1705. doi:https://doi.org/10.1123/ijspp.2022-0160

Chapter 7

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of jockeys in trial and race riding. *Animals,* 12. doi:https://doi.org/10.3390/ani12182351

iv Synopsis

Introduction

This thesis describes the injury risk, performance and career longevity of jockeys in Aotearoa, New Zealand (NZ). Determining the physiological demands and performance characteristics of sporting activities are integral in identifying the general and sport-specific fitness of participants (Douglas, 2017). Jockeys have an integral role in the quality of racing and the welfare of the racehorse, so ensuring they are performing to their best potential is paramount not only for their own performance, injury risk and career longevity, but will also impact on the horses they ride. The future development, prescription, and execution of successful training interventions for jockeys, in combination with monitoring training progress, depend on detailed knowledge of racing specific physiological demands.

Whilst there is a plethora of information about horse performance (Hodgson *et al.*, 2014), less is known about the physiological demands of jockeys or how the jockeys' body displacement and muscle activity can influence horse performance or jockey fatigue and ultimately, race performance, injury risk and career longevity for jockeys during racing (Cullen *et al.*, 2015). Sport and role specific training programmes traditionally aim to target the muscle groups involved in the role or sport and to improve performance, but little is known about the differences between training and competition demands in race riding jockeys and how training may reduce risk of injury, enhance performance, or influence career longevity. Additionally, there has been limited attention paid to the risk factors for jockeys being dislodged during a race or having a horse fall.

Aims

The overall aims of this thesis are to describe the injury risk, performance, and career longevity of jockeys in relation to their overall and specific training and competition level physiological[1] demands. Specifically, the aims are:

- Chapter Two – Risk factors for jockey falls

  To determine the incidence of, and risk factors for, race-day jockey falls in Thoroughbred flat and jumps (hurdle and steeplechase) racing.

  - *Hypothesis* – Jockey experience and lack of fitness are risk factors for jockey race day falls

- Chapter Three – Jockey external workload

  To quantify the competition level (external) workload of jockeys identifying relationships to their experience and performance.

  - *Hypothesis* – jockeys with higher competition level workloads are more experienced, successful and have less falls than jockeys with lower workloads.

- Chapter Four – Jockey career length

  To determine the career lengths and risk factors for loss from the industry of Thoroughbred racing jockeys in New Zealand.

  - *Hypothesis* – jockeys with longer careers have more rides, fall less often, and are more successful than shorter career jockeys.

- Chapter Five – Physical activities of jockeys

[1] Physiological demands in this context have been used throughout this document to describe cardiovascular demand, as assessed through measurement of Heart Rate (HR).

To quantify the physical activities of jockeys during a working week and to investigate self-reported fall and injury incidence rates of jockeys at work.

  - *Hypothesis* – jockeys do no physical activity other than riding in training or races during a normal week. Jockeys who did less fitness training were more likely to fall in a race.

- Chapter Six – Physiological demands of track-work jockeys

  To quantify the physiological demands and profile the muscle activity of jockeys riding track-work.

  - *Hypothesis* – the physiological demands of jockeys riding track-work are low, with high muscle activity in the jockeys' legs and 'core' to maintain the jockey crouch position.

- Chapter Seven – Physiological demands of trial and race jockeys

  To quantify the physiological demands of jockeys over the course of an entire trial or race day, describe jockey displacements and to profile the muscular activity of jockeys riding in trials and races.

  - *Hypothesis* – the physiological demands of jockeys riding in a trial or race are high, with high muscle activity in the jockeys' legs and 'core' muscles, similar to track-work.

Structure and findings of the thesis

The aims of the thesis are addressed in a literature review and six studies, each of which is described in a separate chapter and has been published (or is in press) as a standalone refereed journal article. Chapter One is a literature review that describes what is known about the physiological demands and performance characteristics of jockeys. Chapters 2 - 5 are the first four of the six studies characterising injury risk, performance, and career longevity of jockeys in relation to their overall level of competitive and training workload. Chapters 6 - 7 are the last two of the six studies characterising the ride specific physiological demands and muscle activity of jockeys in training and race-riding. The final chapter of the thesis (Chapter 8) is a general discussion. It provides a synthesis, discussion, proposals for future work, summary and conclusions. The chapters and their findings are summarised in diagrammatic form (a 'Racetrack diagram') in Figure 1.

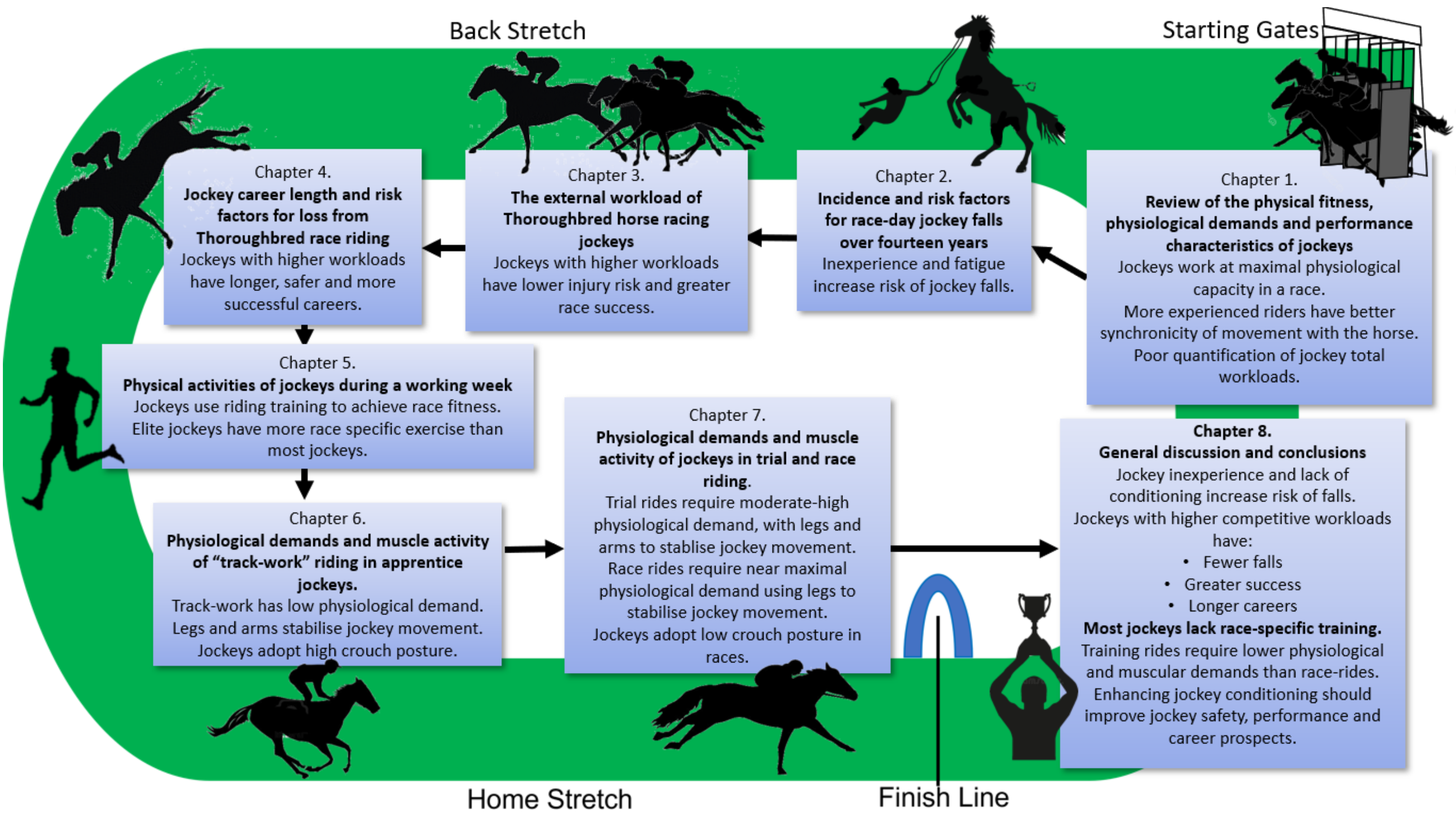

Figure 1. Racetrack diagram of the studies and outcomes of the thesis. Legg, 2022

Chapter One – Review of the physical fitness, physiological demands and performance characteristics of jockeys

Chapter One is a literature review collating information from different equestrian disciplines to describe what is known about the physiological demands, muscle activity and synchronicity of movement of jockeys riding in a race and to identify limitations within our current knowledge. **It found** that jockeys work at their maximal physiological capacity during a race. Synchronous movement with the horse required coordinated muscular activation patterns, particularly in the 'core' and leg muscles with experienced riders showing a higher degree of synchronicity and coordination. **It concludes** that successful training interventions require knowledge of the physiological demands and performance characteristics of the specific sport, however, there was poor quantification of jockey training and racing workloads, particularly in New Zealand.

Chapters 2 – 5 used epidemiological and survey data to provide a starting point for understanding the jockey's training and racing workload.

Chapter Two - Incidence and risk factors for jockey falls over fourteen years.

Chapter Two examines risk factors for jockey falls in New Zealand. All race records (n = 421,596 race starts) over 14 years of Thoroughbred racing in New Zealand (2005 to 2019 racing seasons) including all the records of jockey and horse falls within this timeframe were examined using uni- and multi-variable analyses in generalised linear mixed models. **It found** that during flat racing, the incidence rate of falls (IR) was 1.2 per 1,000 starts. However, while jumps racing only accounted for 3% of the racing starts, the rate of falls was almost 50 times that of flat racing for a hurdles race (53.2 per 1,000 starts and nearly 100 times that for steeplechase races with 99.9 falls / 1,000 starts. Experienced jockeys (and horses) had a lower incidence of falls than inexperienced jockeys. Jockeys with fewer race rides were more likely to have a fall indicating that there may be some need for “race specific fitness”. Incidence rate ratio (IRR) increased linearly with the number of race-day rides, and shorter jumps races were associated with lower IRR of jockey falls. **Chapter Two concludes** that jockey inexperience and fatigue were associated with an increased risk of jockey falls during competitive racing. This highlighted the role that sport specific training may have on reducing injury risk, particularly in inexperienced jockeys.

Chapters Three – The external workload of Thoroughbred horse racing jockeys

Chapter Three quantifies and describes the external (competitive race level) workload of 786 Thoroughbred racing jockeys, who rode in 407,948 flat and 13,648 jumps racing starts over 14 seasons (2005 to 2019 racing seasons), in relation to their experience and racing performance. Jockeys were classified based on jockey work (ride numbers, seasons riding) and performance characteristics (race falls or wins) between cohorts with low (1 - 10), middle (10 - 200) and high (> 200) numbers of rides per season. **It revealed** that jockey rides during the season were typified by a few jockeys (23% of all jockeys) having 83% of all the race rides. Most of the jockeys had light workloads and also had a greater risk of injury and lower winning rates than the smaller cohort of jockeys with heavier workloads. These elite jockeys had half the fall rate per 1,000 rides (Incidence rate [IR] 1.0/1,000, 95% Confidence Interval [CI] 0.9 - 1.1/1,000) and 1.4 times the success rates (IR 98/1,000, 95% CI 97 – 99/1,000) than jockeys in the low and middle workload cohorts ($p < 0.05$). **It concludes** that the disparity in opportunity and success between cohorts indicates there are inefficiencies within the industry in recruitment and retention of jockeys. These data provide a foundation to investigate jockey competition specific fitness and whether training rides provide enough race-specific training.

<u>Chapter Four – Jockey career length and risk factors for loss from Thoroughbred race riding</u>

Chapter Four describes jockey competitive careers lengths and risk factors for loss from the industry using a dataset containing the career history of 786 jockeys, who rode in 407,948 flat and 13,648 jumps racing starts over 14 seasons (2005 to 2019 racing seasons). Descriptors were compared between jockeys in short (1 - 2 years), middle (3 - 9 years) and long (> 10 years) career cohorts with descriptive statistics and Kaplan–Meier survival curves. **It found** that the median (typical) career length for jockeys was 2 years (interquartile range [IQR] 1 - 6). This short career reflected the bias observed in Chapter 3, with the majority of jockeys having very few race rides compared to the elite jockeys who had most of the rides. Jockeys with long race careers (only 11% of all jockeys) were able to ride at lower carried weights (IQR 56 - 57 kg, p = 0.03), had 40 times the number of race rides of the "average" jockey and were 1.3 times more likely to win a race. Forty percent of jockeys failed to complete their apprenticeship, half of which were lost from the industry in their first year of race riding. Jockeys who began their careers under 18 years of age were twice as likely to remain in their career than jockeys who began at an older age (p = 0.02). Therefore, **it concludes** that those few jockeys with higher workloads have longer, safer and more successful careers, highlighting the importance of developing targeted early selection and training criteria for apprentice jockeys.

The subsequent three studies (Chapters 5 – 7) measured the physical activity of jockeys and apprentices during a working week and quantified the intensity of their exercise levels in both training and race riding. The deficit in specific knowledge of physiological demands, performance characteristics and muscle activity of jockeys riding in training and racing was addressed in Chapters 6 - 7. These studies provided real time field data of jockeys riding a normal training or race day.

Chapter Five – Physical activities of jockeys during a working week

Chapter Five quantifies the physical activities (riding and non-riding) of jockeys during a normal working week using a nationwide online survey of 63 jockeys (38% of the licensed jockey population). **It reported** that jockeys worked 6-days per week, riding a median of 7 (IQR 6 - 9) horses each day in training, comprising 58% of work time. Elite jockeys spent more time riding in races, with 29% (IQR 0 - 54%) of their weekly rides as race rides, compared to 4% (IQR 0 – 20%) for the "average" jockey. Extra (non-riding) physical training for most jockeys consisted of low intensity exercise, with these jockeys having race-day fall IRs one third that of jockeys who did no extra physical training. **It concludes** that elite jockeys experienced a level of specific race exercise which was lacking in the majority of jockeys and jockeys who were 'fitter' were less likely to fall on race-day. Jockeys used riding (track-work, trials and races) as the main training exercise to achieve race fitness. This study highlighted the need for data describing the ride level specific physiological demands and performance characteristics of jockeys in both training and race rides.

Chapters Six - Physiological demands and muscle activity of "track-work" riding in apprentice jockeys.

Chapter Six describes the physiological demands, body displacements and muscle activity of 10 apprentice jockeys riding 48 horses in track-work (daily horse training) for their current racehorse trainer. Heart rate (HR), global positioning system (GPS), accelerometer (body displacement) and electromyographic (recording eight muscle groups: *quadriceps,* *hamstrings, gluteal, lower back, obliques, abdominal, trapezial* and *pectoral*) data were collected continuously for the duration of the work period. **It found** that jockeys rode an average of 6 ± 1 horses over ~2.5 hours at a canter speed of 8.8 ± 0.7 $m \cdot s^{-1}$, with mean HRs of 129 ± 11 bpm and rating of perceived exertion (RPE) representing easy/moderate exercise. Jockeys adopted a crouched posture using their legs and arms as stabilisers, minimising their head movement in the medial/lateral and fore/aft planes. There were minimal changes in the muscular activation profile of jockeys either during a ride or over the course of the work. **It concludes** that riding track-work requires a low physiological (aerobic) demand with no evidence of fatigue. However, though track-work riding forms the bulk of a jockeys training load, they also take part in trial and race rides weekly, and these demands required characterisation.

Chapter Seven – Physiological demands and muscle activity of jockeys in trial and race riding.

Chapter Seven describes the physiological demands, body displacements and muscle activity for 12 jockeys riding a typical day in 52 trials and 16 races. HR, GPS, accelerometer (body displacement) and EMG data were collected from jockeys riding for an entire trial (n = 10) or race-day (n = 4) competition. **It revealed** that in trials, jockeys rode an average of 5 ± 4 horses in the space of ~2 hours at a trial gallop speed of 16.5 ± 0.8 $m \cdot s^{-1}$, with mean HRs of 160 ± 17 bpm (~81% HR_{max}) and RPE representing moderate/somewhat hard exercise. In races, jockeys rode an average of 4 ± 2 horses in the space of ~2.5 hours at a race gallop speed of 16.0 ± 0.6 $m \cdot s^{-1}$, with mean HRs of 166 ± 10 bpm (~94% HR_{max}, $p < 0.05$) and RPE representing very hard exercise. Jockey total head displacement was similar in trials and races, although jockeys riding in trials had more vertical and less medial/lateral and fore/aft displacement than jockeys riding in races. Race jockeys adopted a lower crouched posture than those riding in trials, using greater *hamstring* activation and less upper arm muscle activation than in trials. This effectively damped horse oscillation through their legs and minimised vertical head oscillation. There was some evidence of possible fatigue for both trial and race riding jockeys. Therefore, **it concludes** that trial riding required a moderate to high physiological demand, whereas racing demand was near maximal. The differences in physiological demands and muscle activity between trial and race riding jockeys highlighted the differences between riding in training and competition. These data supported the need for jockeys to partake in a specific training programme based on competition level demands which are not currently attained through solely riding training rides.

Chapter Eight – General discussion and conclusions

Chapter Eight (the final chapter) is a synthesis of the findings from the seven chapters in a general discussion. It gives an overview of the physiological demands of jockeys riding in training and racing. The data in Chapters 2 - 4 indicate that the length of a typical jockey's career is very short and is heavily influenced by the ability to obtain race rides early in their career. It appears that higher numbers of race rides not only increase the chance of success, but the higher frequency of race riding may increase "competition fitness" and reduce the risk of injury. These metrics may reflect the biological constraints to which a jockey is subject within the sport of horse racing. Future studies could use these data to model the optimum level of competition specific fitness for a jockey to maintain, to both reduce injury risk and optimise performance, thereby increasing career longevity. If this level of fitness could be achieved through supplementation of race-rides with non horse-based specific training, this may result in a safer sport and safer apprentice training.

The data in Chapters 5 – 7 indicate that jockeys used training rides to gain race fitness, but elite jockeys experience a level of race-specific exercise which was lacking in the majority of jockeys. Race riding requires higher physiological demand and a lower crouched posture with a different muscular activation profile than jockeys riding in track-work and trials. If race-fitness could be trained using off-horse physical training, jockeys could be better physically prepared for competitive race-riding. The differences in posture and physiological demand required by jockeys to ride in a race, as opposed to track-work and trials, provide information which could be used in the design of an off-horse race-specific physical training programme designed to help improve both safety and performance in jockeys. Instigation of a race-specific physical training programme early in the career of an apprentice jockey, with clearly defined milestones, would be likely to help increase retention of high-quality jockeys within the industry as well as help improve both horse and jockey welfare.

Implications

This thesis could be used by the Thoroughbred racing industry as a starting point to develop strategies and policies for minimising the risk of racing injury by increasing jockeys' fitness and ridden position on the horse. By improving the conditioning of jockeys, it is hypothesised that riding performance can be enhanced and the opportunity for jockeys to positively influence horses in race situations will increase. In the long term, this should enhance the jockey's ability to safely and optimally prepare for race riding, reducing the incidence of race day accidents, enhancing both horse and jockey welfare and increasing the career longevity of successful jockeys. In addition to the Thoroughbred racing industry, the methodologies and insights gathered from this thesis could be further applied to explore and enhance rider performance in other equestrian disciplines such as show jumping, eventing and polo.

Conclusions

- Jockeys had a higher IR of falls in flat than jumps races. Jockey inexperience and fatigue were associated with an increased risk of jockey falls during competitive racing.
- Most jockeys had low competitive racing workloads. Jockeys with higher competitive workloads have lower injury risk and greater race success.
- Most jockeys have short (< 2 years) careers. Jockeys with higher competitive workloads have longer, safter and more successful careers.
- Jockeys used riding training as their main form of fitness. A small proportion of elite jockeys experienced a higher level of race-specific exercise than most jockeys.
- Riding track-work requires low physiological demand, with legs and arms working to dampen horse movement and stabilise the jockeys head movement.
- Trial riding requires moderate to high physiological demand. Race riding requires near-maximal physiological demand. Race jockeys adopt a lower crouched posture than those riding in trials, with less vertical head oscillation and greater *hamstring* activation.

Riding training does not approximate race-specific physiological demands. There is a need for race-specific jockey training with clearly defined athletic milestones based on race-riding characteristics. Achieving race specific fitness in readiness for competition is important for jockey safety, performance, and career longevity

Table of Contents

i Abstract .... **i**

ii Acknowledgements .... **iii**

iii Publications .... **v**

Journal articles .... *v*

iv Synopsis .... **vii**

Introduction .... *vii*

Aims .... *viii*

Structure and findings of the thesis .... *ix*

Table of Contents .... **xix**

List of Tables .... **xxiii**

List of Figures .... **xxvi**

List of abbreviations/racing specific terms .... **xxviii**

Introduction **1**

Foreword to thesis chapters *7*

1 Chapter One - Review of physical fitness, physiological demands, and performance characteristics of jockeys **9**

1.1 Abstract *10*

1.2 Introduction *10*

1.3 Methods *14*

1.4 Anthropometric characteristics of jockeys *15*

1.5 Workload of jockeys *17*

1.5.1 Workload constraints 17

1.5.2 External workload 19

1.5.3 Internal workload 20

1.6 Muscle recruitment *21*

1.7 Horse and rider synchronicity *24*

1.7.1 Performance measures 25

1.8 Physical conditioning *26*

1.9 Conclusions *28*

1.10 References *29*

1.11 Epilogue to Chapter One *36*

2 Chapter Two - Incidence and risk factors for race-day jockey falls over fourteen years **39**

2.1 Foreword to Chapter Two *40*

2.2 Abstract *41*

2.3 Introduction *41*

2.4 Methods *44*

2.5 Results *46*

2.5.1 Flat racing 47

2.5.2 Hurdle racing...50
2.5.3 Steeplechase racing...51
2.6 Discussion...53
2.7 Conclusions...58
2.8 Practical implications...59
2.9 References...60

3 Chapter Three - The external workload of Thoroughbred horse racing jockeys...63
3.1 Foreword to Chapter Three...64
3.2 Abstract...65
3.3 Introduction...65
3.4 Materials and methods...68
3.5 Results...70
3.6 Discussion...75
3.6.1 High workload cohort jockeys...77
3.6.2 Limitations...79
3.7 Conclusions...80
3.8 References...81

4 Chapter Four - Jockey career length and risk factors for loss from Thoroughbred race riding...85
4.1 Foreword to Chapter Four...86
4.2 Abstract...87
4.3 Introduction...87
4.4 Materials and methods...90
4.5 Results...91
4.5.1 Apprentices...95
4.5.2 Yearly racing...96
4.6 Discussion...97
4.6.1 Long career cohort jockeys...98
4.6.2 Apprentices...100
4.6.3 Seasonal rides...101
4.7 Conclusions...102
4.8 References...103

5 Chapter Five - Physical activities of jockeys during a working week...107
5.1 Foreword to Chapter Five...108
5.2 Abstract...109
5.3 Introduction...109
5.4 Methods...112
5.4.1 Participants...113
5.4.2 Statistical Analysis...114
5.5 Results...115
5.5.1 Participants...115
5.5.2 Work and exercise...116
5.5.3 Falls and injury...119
5.6 Discussion...121
5.6.1 Work and exercise...123
5.6.2 Falls and injury...126
5.7 Conclusions...128
5.8 References...129

6 Chapter Six - Physiological demands and muscle activity of "track-work" riding in apprentice jockeys....133
6.1 Foreword to Chapter Six...134

6.2 Abstract ... *135*
6.3 Introduction ... *135*
6.4 Methods ... *138*
6.4.1 Participants ... 138
6.4.2 Data collection ... 138
6.4.3 Statistical analysis ... 140
6.5 Results ... *142*
6.5.1 Accelerations and muscle activity ... 144
6.6 Discussion ... *149*
6.6.1 Practical Applications ... 153
6.7 Conclusions ... *153*
6.8 References ... *155*

7 Chapter Seven - Physiological demands and muscle activity of jockeys in trial and race riding. ... 159
7.1 Foreword to Chapter Seven ... *160*
7.2 Simple Summary ... *161*
7.3 Abstract ... *161*
7.4 Introduction ... *162*
7.5 Methods ... *166*
7.5.1 Subjects ... 166
7.5.2 Data collection ... 166
7.5.3 Statistical analysis ... 169
7.6 Results ... *171*
7.6.1 Accelerations and muscle activity ... 173
7.7 Discussion ... *178*
7.7.1 Limitations ... 185
7.8 Conclusions ... *187*
7.9 References ... *189*

8 Chapter Eight – General discussion and conclusions ... 193
8.1 Physical training ... *194*
8.1.1 Optimum training load ... 196
8.2 Career pathway ... *199*
8.3 Strengths and limitations ... *201*
8.4 Recommendations for future studies ... *205*
8.5 Thesis summary ... *209*
8.6 Conclusions ... *210*

9 References ... 213

Appendices ... 220

Appendix A Univariable table of risk factors for jockey falls in flat races ... 221

Appendix B Univariable table of risk factors for jockey falls in hurdle races ... 223

Appendix C Univariable table of risk factors for jockey falls in steeplechase races ... 225

Appendix D Jockey workload diary ... 227

Appendix E Horse Pull and Borg RPE rating scale ... 240

Appendix F Mean linear accelerations and displacements of horse and jockey during trials and races **242**

Appendix G Ethical approval documentation **243**

Appendix H Participant information sheet **245**

Appendix I Participant consent form **250**

Appendix J Statements of contributions to research **251**

List of Tables

Table 1.1 Anthropometric characteristics (mean ± standard deviation) of jockeys and apprentices. 16

Table 2.1 Summary data, incidence rates (IR) and incidence rate ratios (IRR) for jockey falls occurring in flat, hurdle and steeplechase racing in New Zealand from 2005/6 – 2018/19 racing seasons (95% CI in brackets) 46

Table 2.2 Multivariable Poisson regression of association between jockey falls in flat races and predictor variables; season of the year, horse age, carried weight (kg), flat rating (of horse), maximum number of race-day rides and the number of races previously ridden by the jockey on a race-day. 49

Table 2.3 Multivariable Poisson regression of association between jockey falls in hurdle races and predictor variables; race distance (m), track condition (fast, good, dead, slow or heavy), weight carried during the race, hurdles rating of the horse and maximum number of race-day rides by the jockey. 51

Table 2.4 Multivariable Poisson regression of association between jockey falls in steeplechase races and predictor variables; season of the year, jockey experience (apprentice or jockey), steeples rating of the horse, jockey age and maximum number of race-day rides by the jockey. 53

Table 3.1 Median and interquartile range (IQR) numbers of seasons riding, rides per race day, race days and rides per season for jockeys and apprentices stratified by race type from 1 August 2005 – 17 April 2019. 71

Table 3.2 Characteristics of jockeys with low (1 - 10 or 1 - 5), middle (10 - 200 or 5 - 25) and high (> 200 or > 25) number of rides per season stratified by flat and jumps racing, respectively, from 1 August 2005 – 17 April 2019. 73

Table 4.1 Characteristics of flat racing jockeys with short (1 - 2 years), middle (3 - 9 years) and long (>10 years) career lengths for the 2005/6 - 2018/9 racing seasons. 93

Table 5.1 Characteristics (median and interquartile range) of 33 professional jockeys, 25 apprentices and 5 amateur riders licensed in New Zealand during 2020. 115

Table 5.2 Number of hours per week (median and IQR) engaged in physical activities for jockeys licensed in New Zealand during 2020, stratified by license type (professional, apprentice and amateur) and riding level. 117

Table 5.3 Exercise volume (hours) per week (median and IQR) for jockeys who engaged in out of work physical activity, stratified by license type (professional, apprentice and amateur) and riding level. 119

Table 5.4 Self-reported falls and injury requiring time off work incidence rates (IR with 95% CI) of licensed professional jockeys, apprentices and amateur riders during morning exercise work and race riding in New Zealand during 2020. 121

Table 6.1 Descriptive data (mean ± SD) for apprentice jockeys (n = 10)..............................142

Table 6.2 Time allocation and internal load during a typical morning riding track-work for n = 10 apprentice jockeys (mean ± SD). 143

Table 6.3 Descriptive data (mean ± SD) of the characteristics of track-work and internal load per ride (n = 48). 144

Table 6.4 Mean (± SD) linear accelerations and displacements of horse (n = 48) and jockey's head (n = 10) during morning track-work. 145

Table 6.5 Mean (± SD) magnitude of displacements (m) of horse and jockey for within a ride (n = 48) and between the first and last ride (n = 10) during morning track-work. Effect sizes are between the horse and jockeys' head or first and last section. 146

Table 6.6 Mean (± SD) surface EMG parameters of eight muscle groups for jockeys (n = 10) riding track-work (n = 48). 148

Table 6.7 Mean (± SD) muscle activity (%) of jockeys within a ride (n = 48) and between the first and last ride (n = 10) during morning track-work. Effect sizes are between the first and last sectional of the ride. 148

Table 7.1 Descriptive data (mean ± SD) for apprentice (n = 8) and senior (n = 4) jockeys ...171

Table 7.2 Time allocation and HR (mean ± SD) during a day at the trials (n = 10) or races (n = 4) for 12 jockeys (n = 8 trials, n = 4 races). 172

Table 7.3 Descriptive data (mean ± SD) of the characteristics of sectionals and entire trial (n = 52) and race (n = 16) rides and corresponding jockey physiological response per ride. 173

Table 7.4 Mean (± SD) magnitude of displacements (m) of horse and jockey for within a trial (n = 48) or race (n = 16) and between the first and last ride (n = 10, trials, n = 4 races). Effect sizes are between horse displacement at trials and jockeys' head or start and end sectionals. 176

Table 7.5 Mean (± SD) surface EMG parameters of eight muscle groups for jockeys (n = 12) riding in trials (n = 48) and races (n = 16). 177

Table 7.6 Mean (± SD) muscle activity (%) of jockeys within a ride (n = 48 trials, n = 16 races) and between the first and last ride during trials (n = 48) and races (n = 16). Effect sizes are between the first and last sectional of the ride. 178

Table A.1 Univariable Poisson regression of association between jockey falls in flat races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, flat rating (of horse), number of starters, jockey gender and age, maximum number of race day rides and the number of races previously ridden by the jockey on a race day. 220

Table B.1 Univariable Poisson regression of association between jockey falls in hurdle races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, hurdles rating, number of starters, jockey gender and age, maximum number of race day rides and the number of races ridden previously by the jockey on a race day. 222

Table C.1 Univariable Poisson regression of association between jockey falls in steeplechase races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, hurdles rating, number of starters, jockey gender and age, maximum number of race day rides and the number of races ridden previously by the jockey on a race day. 224

Table E.1 Horse pull rating scale and Borg's rating of perceived exertion 10-point scale used with jockeys (n = 10) to score each ride of a morning's track-work. Adapted from (Borg, 1982) 239

Table F.1 Mean (± SD) linear accelerations and displacements of horse (n = 32) and jockey's head during trials (n = 48) and races (n = 10). 241

List of Figures

Figure 1. Racetrack diagram of the studies and outcomes of the thesis. Legg, 2022 x

Figure 2. Vertical (y), fore/aft (x) and medial/lateral (z) measurement planes relative to the horse and jockey..xxx

Figure 3. Placement of accelerometers (A) and EMG (B) on horse and jockey during field studies in chapters 6 and 7..xxx

Figure 1.1 Different riding positions. (A) modern jockey position; (B) forward or two-point riding position; (C) seated or three-point position. *Photos by Kylie Legg.* 12

Figure 2.1 Jockey race day fall incidence rate (IR) occurring in flat, hurdle and steeplechase racing in New Zealand from the 2005/6 - 2017/18 racing seasons. 47

Figure 3.1 Median number of rides for flat racing jockeys and apprentices from 1 August 2005 – 31 July 2018. 72

Figure 3.2 Percentages of flat racing jockeys and total number of flat racing rides for low (1 - 10), middle (10 - 200) and high (> 200 rides per season) workload cohort jockeys from 1 August 2005 - 17 April 2019. 74

Figure 3.3 Numbers of flat racing jockeys in low (1 - 10), middle (10 - 200) and high (> 200 rides per season) cohorts from 1 August 2005 – 17 April 2019..75

Figure 4.1 Number of seasons riding for flat and jumps racing jockeys for the 2005/6 - 2018/9 racing seasons. 92

Figure 4.2 Length of career of flat racing jockeys who first appear in low (1 - 10 rides/season, n = 335), middle (10 - 200 rides, n = 244) or high (>200 rides, n = 78) workload cohorts for the 2005/6 - 2018/9 racing seasons. Shaded area indicates 95% confidence interval. 95

Figure 4.3 Career survival probability for apprentices that completed their apprenticeship (n = 131) and those that did not (n = 200) for the 2005/6 - 2018/9 racing seasons. Shaded area denotes 95% confidence interval...96

Figure 4.4 Number of monthly flat racing ride opportunities for the 2005/6 - 2018/9 racing seasons 97

Figure 6.1 Mean magnitude of displacements relative to the horse of jockey riding track-work, and in the vertical (y), fore/aft (x) and medial/lateral (z) planes. * Denotes significant differences between jockey and horse displacement ($p < 0.05$). 146

Figure 7.1 Mean magnitude (M) of displacements (cm) and relative displacement (%) of jockey to a horse galloping at (A) Trials and (B) Races, and in the vertical (y), fore/aft (x) and medial/lateral (z) planes. Horse displacements were measured only for horses racing in trials. All differences between jockey and horse (at trials) displacement are significant (p < 0.05). * denotes differences between jockey displacement in trials and races (p < 0.05)..175

Figure 8.1 Conceptual framework model of the relationship between training load and jockey experience based on the athlete development pathway to optimise a successful and sustainable career in jockeys. (Legg, 2022, adapted from Balyi *et al.* (2004)). 198

List of abbreviations/racing specific terms

ANOVA	Analysis of variance.	
BMI	Body Mass Index, calculated as the ratio of the weight to the square of height in metres ($kg \cdot m^{-2}$).	
CNS	Central nervous system.	
COM	Centre of mass.	
Elite jockey	Those jockeys who rode in > 200 rides per season or were identified as being in the top 20 jockeys (or apprentices) in the New Zealand premiership table published by NZTR which provides rankings based on jockey performances throughout the season.	
EMG	Electromyography – Measurement of the electrical activity of a muscle in response to the nerve's stimulation of a muscle.	
ES	Cohens Effect Size, used to determine differences between groups by calculating the difference between the means divided by the pooled standard deviation.	
FEI	Fédération Équestre Internationale – the international governing body of equestrian sports.	
GPS	Global positioning system.	
HR	Heart rate measured in beats per minute (bpm).	
	HR_{max}	Estimated maximum HR based on subjects age (HR_{max} = 220 – age).
	HR_{peak}	Maximum HR recorded (bpm).
IQR	Interquartile range.	
IR	Incidence rate per 1,000 racing starts.	
IRR	Incident rate ratio.	
Jump outs	Unofficial training days for horses to gallop a set distance after 'jumping out' the starting gates.	
Licence type	Apprentice	Young, inexperienced jockeys, aged over 15 years, serving a 4-year apprenticeship, working their way up to professional jockey status by riding with and competing against professional jockeys in trials and races.

	Probationers: Pre-apprenticeship licence, allowing the holder to compete a horse in trials, held for 3 – 12 months.
	Professional: Jockeys (> 18 years of age) who have served their 4-year apprenticeship to become professional jockeys.
	Track riders: Licence held by all riders to enable them to ride a horse in training on the racetrack and in jump-outs.
NZTR	New Zealand Thoroughbred racing, the governing body for racing in New Zealand.
Pace work	Horse training at a slow training pace, usually canter at 7 - 9 $m \cdot s^{-1}$.
Racing season	1 August – 31 July in New Zealand.
Racecourse steward	Stewards oversee all aspects of horse racing and wagering within the sport to ensure that the regulations and guidelines are adhered to.
Riding mentor	NZTR Approved riding instructor responsible for coaching apprentices in race riding.
RPE	Rating of Perceived Exertion, based on the 10-point category scale (Borg, 1982).
Schoolmaster	A horse with the experience and the ability to help a rider learn and perfect riding skills.
SD	Standard deviation.
Senior jockey	Same as professional jockey.
Track-work	Daily horse training, usually consisting of a walk to the track, 2 – 3 laps at canter around the training track or a gallop and a walk home.
Trials	Official mock races with no gambling allowed.
TRIMP	Training impulse. TRIMP scores were calculated by summing the accumulated time (minutes) spent in five different HR zones according to Edwards (1993).
$\dot{V}O_{2\,max}$	Maximal oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$).
	pred$\dot{V}O_{2max}$: predicted maximal oxygen uptake, estimated from the participants running the multistage 20 m shuttle test (beep test) (Leger *et al.*, 1988).

Figure 2 depicts the measurement planes referred to throughout the study. Figure 3 depicts the placement of measurement devices on the jockey and horse in chapters 6 – 7.

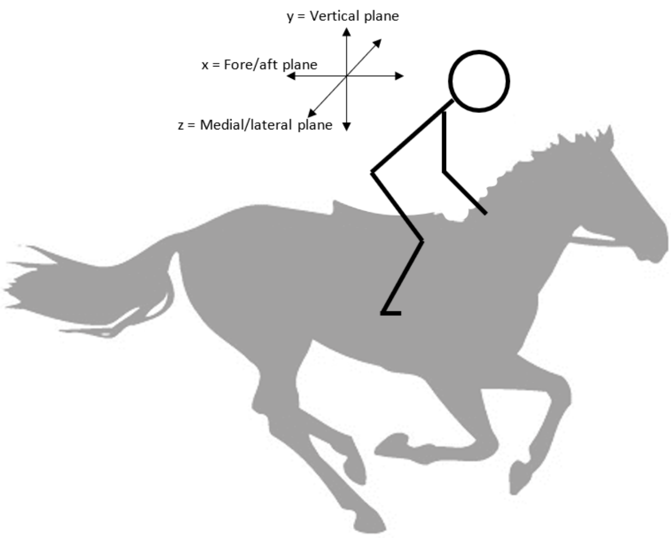

Figure 2. Vertical (y), fore/aft (x) and medial/lateral (z) measurement planes relative to the horse and jockey.

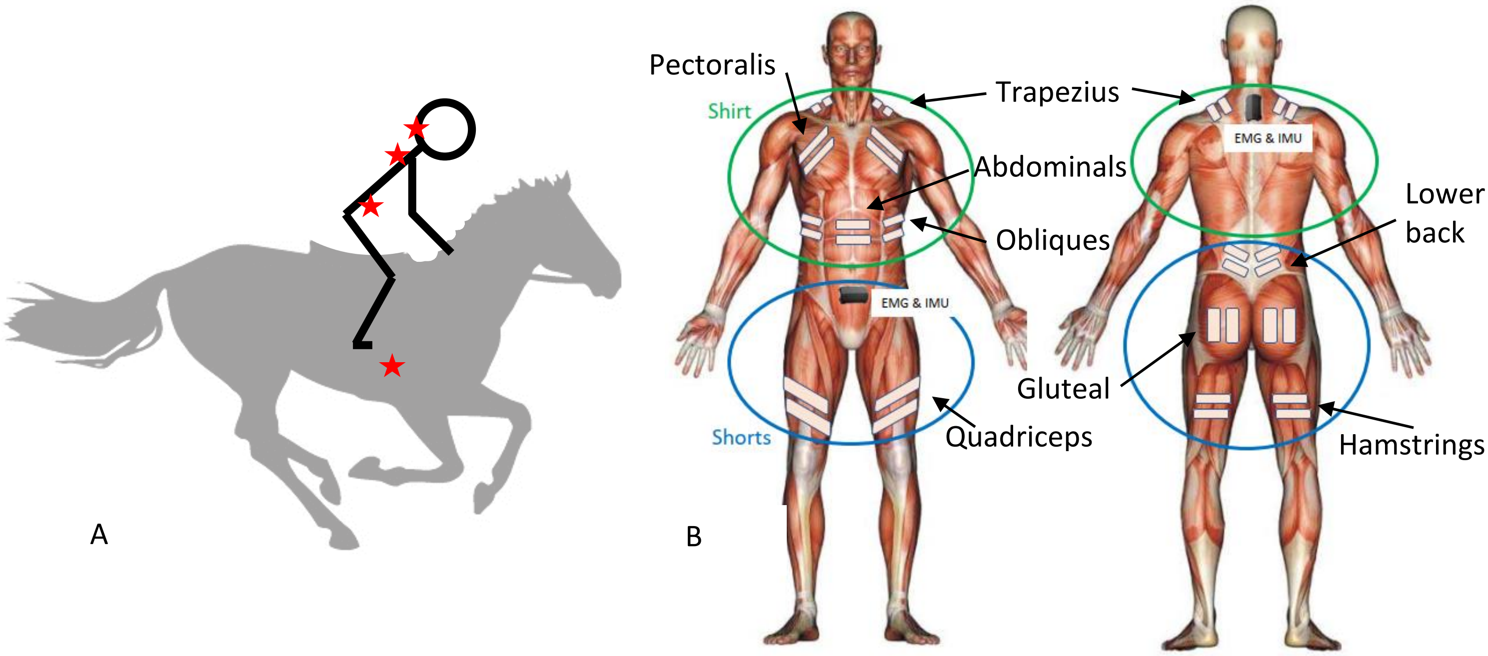

Figure 3. Placement of accelerometers (A) and EMG (B) on horse and jockey during field studies in chapters 6 and 7.

Introduction

The Thoroughbred racehorse industry is of major economic importance worldwide. In 2019, there were 148,179 Thoroughbred races held in 50 countries with approximately a quarter of a million different horses starting in races with total prize monies of approximately €3,349 million (International Federation of Horse Racing Authorities, 2019). The economic impact of the racing industry in the United States (USA) is estimated to be US$26.1 billion (Peterson *et al.*, 2008) and it is one of the largest industries in Australia, contributing 0.5% to gross domestic product (GDP) (Bailey *et al.*, 1997). In New Zealand, the racing sector is estimated to generate over NZ$1.4 billion yearly (approximately 1%) in GDP (Bolwell *et al.*, 2017).

All sports that involve the use of animals need to consider the social license within which they operate. Social license considers the role of the community or wider society in sanctioning or censuring activities, such as equine sport, and reflects the changing attitudes of society. The challenges for racing are that when accidents occur on race day the implications to horse and jockey can be severe and the graphic images can be widely spread through both mainstream and social media (Legg *et al.*, 2019). As an industry, proactive measures are required to ensure public confidence that horse and jockey welfare are considered. Historically, risk factors for horse injury have been examined, but there are limited data on how to reduce jockey fatigue and associated race day accidents. This is surprising given the primary role the jockey has in reducing the risk of injury to a horse during a race. Indeed, more experienced riders have been shown to have a lower risk of falling and have a lower risk of fatal limb fractures in the racehorses they ride compared to jockeys with less experience (Hitchens *et al.*, 2012; Parkin *et al.*, 2004). Within this context, the economic cost of injury to horse or jockey is a significant factor, potentially curtailing the careers or even lives of either or both athletes. A reduction in injuries would thus have mutual humanitarian, animal welfare and financial benefits to all participants in the Thoroughbred racing industry.

Currently, there are 67 Thoroughbred racing clubs, and approximately 500 race meetings held annually in New Zealand, employing ~ 35,000 people with over 800 trainers, 190 jockeys and 5,800 horses contributing to over 32,000 race starts in flat and jumps racing each season (Bolwell *et al.*, 2016; Bolwell *et al.*, 2017; IER, 2018; Perkins *et al.*, 2005; Rosanowski *et al.*, 2015). Interest in the sport is high, and although there are no accurate present day figures of attendances at race meets, it has been estimated that over 350,000 people attended Thoroughbred race meetings throughout New Zealand in 2016/17 (IER, 2018). Due to media reporting and off course gambling opportunities, support for the sport is likely to be much greater than this (McManus *et al.*, 2014).

The temperate climate of New Zealand permits racing year-round on approximately 50 different 1,800 m turf tracks, with generally consistent dimensions and surfaces (Rogers *et al.*, 2014). A Thoroughbred horse's race training includes daily 'track-work' (at a racetrack or home track) at a slow canter, interspersed with training days such as 'jump-outs' and 'trials' to prepare them for an official race day competition. Jump-outs are unofficial training activities where groups of horses 'jump out' from starting gates and gallop a set distance, used primarily to improve horses' fitness or to educate young horses. Trials are official mock races but without the pressure of result driven outcomes. The aim of both is to give the horse a gallop under similar conditions to a race, and jockeys compete to obtain rides in both events.

In New Zealand, the primary focus is flat racing (96% of all races run during a year) (Bolwell *et al.*, 2016). Jumps races take place in the winter season, are longer than flat races, and includes two separate events – hurdle and steeplechase, each with different types of obstacle. Most races in New Zealand are handicap races, enabling equal competition between horses, as higher weights are allocated to better performing horses to equalise the chances of all competitors (New Zealand Thoroughbred Racing, 2019a). This system requires jockeys to be able to meet the specific weight allocated to the horse they ride.

New Zealand Thoroughbred Racing (NZTR) is the governing body for racing in New Zealand. It provides the day-to-day regulation and management of the Thoroughbred industry. NZTR are responsible for the regulation of jockey, apprentice, and trainer licences, as well as development of their training programmes and education. Jockeys in New Zealand can be separated into the following categories: amateur, apprentice, jumps and professional. Amateur jockeys ride in a limited number (n = 15) of amateur races without payment. Apprentice jockeys are young (minimum 15 years of age) flat racing jockeys, who are given a weight allowance of 1 - 4 kg to compensate for their inexperience in race riding (New Zealand Thoroughbred Racing, 2019a). This allowance is reduced with the number of their previous wins. Jumps category licences are given to apprentice or amateur jockeys who are 18 years or over and satisfy NZTR requirements of riding competency. Professional jockeys must be 18 years of age or over and have completed a four year apprenticeship (New Zealand Thoroughbred Racing, 2019c). In the 2018/19 racing season, there were 146 jockeys who won at least one race and 47 registered apprentices.

Apprenticeships in New Zealand are completed in four years full time, and apprentices are employed with an NZTR approved Thoroughbred trainer who is chiefly responsible for their training, development, well-being and assistance in obtaining race-day rides. The riding competency for an apprentice jockey to progress to race-riding is assessed between the NZTR regional riding mentor and the local racecourse stewards. An aspiring apprentice jockey must first obtain a "track riders" licence, where their competency to handle a horse at a training pace (canter) is assessed by the regional NZTR riding mentor. Secondly, they may progress to a 'probationer's' licence where their riding competency is assessed by local racecourse stewards at a number (at the stewards' discretion) of jump-outs, as well as passing a medical and base line concussion test. A probationer's licence allows the aspiring apprentice jockey to compete in trials and is held for a minimum period of 3 months (maximum 12 months). During this period, they must ride in a minimum of 25 satisfactory trial rides (assessed by both their NZTR regional riding mentor and local stewards) before advancing to an apprentice licence and the ability to ride in an official race day alongside professional jockeys. As an apprentice jockey, apprentices must attend the 'Apprentice Academy' which provides up to 60 hours annual off-job training including technical riding instruction on a mechanical horse and reviews of recent race rides, as well as education towards the National Certificate in Equine (level 4) a compulsory component of becoming a licensed jockey (New Zealand Thoroughbred Racing, 2019b). This qualification provides jockeys with the knowledge and skills to manage and care for a horse (including health, anatomy and training) and their equipment, as well as an understanding of the NZTR industry structure and judicial system. It includes a basic foundation in self-management, including nutritional requirements and stress management (New Zealand Qualifications Authority, 2018). However, it does not yet contain any specific fitness requirements or guidelines (other than riding competency).

The reason that the qualification does not contain any specific fitness requirements or guidelines (other than riding competency) for apprentices in New Zealand is that currently, there is a paucity of information pertaining to the nature of the workload or physiological demand of jockeys training and racing in New Zealand, on which fitness training or guidelines can be tailored to the New Zealand industry. This information may additionally have wider application for multiple equestrian disciplines, such as show jumping, eventing and polo. Therefore, the overall aims of this thesis are to describe the injury risk, performance, and career longevity of jockeys in relation to their overall training and competition level physiological demands[2]. The specific aims are:

- Chapter Two – Risk factors for jockey falls

  To determine the incidence of, and risk factors for, race-day jockey falls in Thoroughbred flat and jumps (hurdle and steeplechase) racing.

  - *Hypothesis* – Jockey experience and lack of fitness are risk factors for jockey race day falls

- Chapter Three – Jockey external workload

  To quantify the competition level (external) workload of jockeys identifying relationships to their experience and performance.

  - *Hypothesis* – jockeys with higher competition level workloads are more experienced, successful and have less falls than jockeys with lower workloads.

- Chapter Four – Jockey career length

  To determine the career lengths and risk factors for loss from the industry of Thoroughbred racing jockeys in New Zealand.

  - *Hypothesis* – jockeys with longer careers have more rides, fall less often, and are more successful than shorter career jockeys.

- Chapter Five – Physical activities of jockeys

[2] Physiological demands in this context have been used throughout this document to describe cardiovascular demand, as assessed through measurement of Heart Rate (HR).

To quantify the physical activities of jockeys during a working week and to investigate self-reported fall and injury incidence rates of jockeys at work.

  - *Hypothesis* – jockeys do no physical activity other than riding in training or races during a normal week. Jockeys who did less fitness training were more likely to fall in a race.

- Chapter Six – Physiological demands of track-work jockeys

  To quantify the physiological demands and profile the muscle activity of jockeys riding track-work.

  - *Hypothesis* – the physiological demands of jockeys riding track-work are low, with high muscle activity in the jockeys' legs and 'core' to maintain the jockey 'crouch' position.

- Chapter Seven – Physiological demands of trial and race jockeys

  To quantify the physiological demands of jockeys over the course of an entire trial or race day, describe jockey displacements and to profile the muscular activity of jockeys riding in trials and races.

  - *Hypothesis* – the physiological demands of jockeys riding in a trial or race are high, with high muscle activity in the jockeys' legs and 'core' muscles, similar to track-work.

The aims of the thesis are addressed in the following chapters, comprising of a literature review and six experimental studies, each of which is described in a separate chapter.

Foreword to thesis chapters

Five of the seven chapters in this thesis have been published in refereed journals as standalone papers. One is in press, and one is currently under review. Since the papers are reproduced in full in this thesis, this has resulted in some repetition in the information presented. To comply with the University's requirements for the thesis, some post-publication formatting changes have been made to the papers to ensure consistency among the chapters. These changes are considered to be typographical and have not made any difference to the outcomes of any of the papers.

The thesis chapters contain short forewords or epilogues as appropriate. These provide the logic thinking underpinning the linkages between chapters and are designed to help explain the rationales underlying the aims of the studies.

1 Chapter One - Review of physical fitness, physiological demands, and performance characteristics of jockeys

Published in part in the following publication:

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Review of physical fitness, physiological demands and performance characteristics of jockeys. *Comparative Exercise Physiology*, 17(4), 319-329. doi:https://doi.org/10.3920/CEP200079

1.1 Abstract

This narrative review collates data from different equestrian disciplines, both amateur and professional, to describe the physiological demands, muscle activity and synchronicity of movement involved in jockeys riding in a race and to identify limitations within our current knowledge. A literature search was conducted in Web of Science, Google Scholar, PubMed and Scopus using search terms related to jockeys, equestrian riders and their physiological demands, muscle use, movement dynamics and experience. Abstracts, theses and non-peer reviewed articles were excluded from the analysis. Jockeys work at close to their physiological capacity during a race. The quasi-isometric maintenance of the jockey position requires muscular strength and endurance, specifically from the legs and the core, both to maintain their position and adapt to the movement of the horse. Synchronous movement between horse and rider requires a coordinated activation pattern of the rider's core muscles, resulting in less work done by the horse to carry the rider, possibly leading to a competitive advantage in race riding. Reports of chronic fatigue in jockeys demonstrate poor quantification of workload and recovery. The lack of quantitative workload metrics for jockeys' limits calculation of a threshold required to reach race riding competency and development of sport-specific training programmes. Until the sport-specific demands of race riding are quantified, the development of evidence-based sport specific and potentially performance enhancing jockey strength and conditioning programmes cannot be realised.

1.2 Introduction

All equestrian sports are unique as an activity during which two athletes (horse and human) work together to achieve success. Jockeys have the responsibility of controlling both their individual riding performance as well as the performance of the horse (Pfau *et al.*, 2009), reaching speeds exceeding 60 km·h^{-1} on race day (Warrington *et al.*, 2009). Full time professional jockeys are elite athletes, and race riding requires physical strength, stamina, and the ability to make decisions quickly during a physically demanding race (Cullen *et al.*, 2015; Dolan *et al.*, 2013; Trowbridge *et al.*, 1995; Wilson *et al.*, 2013). The jockeys support themselves in a crouched posture over the horse's withers, with only a small portion of the base of their foot in contact with the stirrup, resulting in a continuous state of quasi-isometric movement. Maintaining their balance in this position requires great muscular strength and endurance. Unsurprisingly, this position evokes a high aerobic and anaerobic response in jockeys (Cullen *et al.*, 2015; Trowbridge *et al.*, 1995).

The modern jockey position (Figure 1.1) was introduced in the 19th Century and has been accredited with a 5 - 7% reduction in race times (Pfau *et al.*, 2009). The position is purported to enable jockeys to isolate their centre of mass (COM) movement from that of the horse, absorbing the vertical movement of the horse in their legs. Jockeys maintain their COM as close as possible to the horses' midline, accounting for the horses' movement with asymmetrical stirrup forces, cranial-caudal (fore/aft) displacement and vertical movement simultaneously (Walker *et al.*, 2016). This requires continuous muscle activity alterations in the jockey to adapt to the characteristics of the different gaits, developing movement specific muscle memory. Maintenance of a consistent position of a jockey's COM relative to the horse both improves jockey balance and reduces the detrimental effect of load carrying on the horse (Pfau *et al.*, 2009; Walker *et al.*, 2016).

Figure 1.1 Different riding positions. (A) modern jockey position; (B) forward or two-point riding position; (C) seated or three-point position. *Photos by Kylie Legg.*

In English riding, horse and rider compete together in a seated (three-point) or a 'forwards' (two-point) stance (Figure 1.1) (Peham *et al.*, 2010), in a range of disciplines including dressage, show jumping and eventing (a combination of dressage, show jumping and cross country jumping). Due to the lack of jockey specific research, similarities between jockeys and riders may be drawn from sport specific requirements, specifically, the adaptation of the jockey to the movement of the horse. Throughout this review, the term 'rider' is used to describe a rider in an English equestrian sport discipline, whereas 'jockey' specifically relates to competitive race riding.

Thoroughbred racing jockeys compete in a high-risk sport (Hitchens *et al.*, 2012). An unexpected movement from the horse can propel the jockey onto the ground from a height of 2 - 3 m at high speed (Press *et al.*, 1995). Falling from a horse is the major cause of injury to jockeys (Curry *et al.*, 2016; Press *et al.*, 1995; Waller *et al.*, 2001) and the jockey has a significant role in reducing the risk of injury to a horse during a race. Studies in Australasia and Ireland have identified that jockey falls were associated with a combination of jockey (gender, experience, previous rides), horse (age, rating, race grade) and environmental (track distance, condition, field size) factors; and both jockey and horse inexperience were positively associated with jockey falls (Hitchens *et al.*, 2010; Legg *et al.*, 2020b; O'Connor *et al.*, 2018;

Proudman *et al.*, 2004). Indeed, more experienced jockeys have been shown to have a lower risk of falling and have a lower risk of fatal limb fractures in the racehorses they ride, compared to jockeys with less experience (Hitchens *et al.*, 2012; Legg *et al.*, 2020b; Parkin *et al.*, 2004).

In English horse riding, approximately 100 hours of riding experience for a naïve rider has been shown to be necessary to produce a substantial decline in injury incidence, with a further reduction in injury incidence after 5 years of experience (Mayberry *et al.*, 2007). By the time apprentice jockeys start race riding, they are at a significantly higher competency level (able to control a horse at canter and gallop) than naïve equestrian riders, but this metric does provide an initial guide as to probable time frames, or level of exposure required to achieve this threshold. If race riding was taken as a separate discipline to riding or daily race training (due to the speed, intensity and specific physical demands posed by race riding as opposed to riding a horse in training (Kiely *et al.*, 2019), one hundred hours would equate to approximately 1,200 race rides (of 5 minutes duration) to achieve race riding competency. During a 4-year apprenticeship, the 12% of New Zealand (NZ) apprentices who rode in over 200 races per season reached this threshold and had a lower fall incidence rate than the majority of apprentices who rode between 7 – 97 races per season and would not achieve even half the number of rides (Legg *et al.*, 2020a). Though this figure is likely to be exaggerated, due to both the large amount of time apprentices spend riding horses in daily training and their high initial skill levels, it provides a useful preliminary metric to quantify the threshold for jockeys to achieve race riding competency and highlights the importance of appropriate and sufficient training for jockeys embarking on a professional sport career.

The jockey is central to the sport of Thoroughbred racing. An unconditioned jockey may not be able to maintain their balance and strength for sustained periods. Peripheral fatigue would reduce their ability to maintain a good posture whilst racing, potentially increasing the risk of injury, and likely be detrimental to the horse's performance (Douglas *et al.*, 2012). Central fatigue has been linked to cognitive performance impairments (Landolt *et al.*, 2017), which may have implications for jockeys coping with the high-speed technical demands of riding and split-second decision making in races.

Whilst there is a plethora of information about horse performance, less is known about the physiological demands of jockeys or how the dynamics of jockey and horse synchronicity can influence horse performance or jockey fatigue (Cullen *et al.*, 2015). Sport and role specific training programmes traditionally aim to target the muscle groups involved in the role or sport and to improve performance. However, improving jockey-horse synchronicity has seldom been considered as a means of enhancing performance and to reduce risk of injury. The aim of this review was to integrate the existing literature on the physical fitness, physiological demands and performance characteristics of jockeys with special attention directed to their muscle activity and synchronicity with the horse.

1.3 Methods

A literature search was conducted in four main databases: Web of Science, Google Scholar, PubMed and Scopus. These databases were searched with the main key words 'jockey' or 'rider' combined with each of the following: 'horse racing', 'physiol*', 'physical demands', 'fitness', 'workload', 'muscle', 'EMG', 'biomech*', 'coordinat*', 'synchronicity', 'posture' and 'skill'. Peer reviewed articles in scientific publications and conference proceedings published up to September 2020 were included in this review. The findings from these articles were summarised and synthesized to form this narrative review.

1.4 Anthropometric characteristics of jockeys

Jockeys worldwide compete under strict weight restrictions, and thus have relatively uniform anthropometric characteristics (Table 1.1) which place them at the 5th percentile for height, weight and Body Mass Index (BMI) when compared to the population norm for British male adults (Pheasant and Haslegrave, 2006), and similar to that observed in elite senior female Chilean gymnasts (Arriaza et al., 2016). Thoroughbred racing is divided into flat and jumps racing. Flat racing takes place over shorter distances (~1,200 – 2,700 m) than jumps racing (~2,900 – 6,400 m) (Bolwell et al., 2016; Hitchens et al., 2010; O'Connor et al., 2018). Flat racing horses carry lower weights (~52 kg vs 64 kg) (Bolwell et al., 2016), and this is reflected in the characteristics of flat racing jockeys, who are significantly shorter in stature, lighter and leaner in body composition than jumps racing jockeys (Warrington et al., 2009). Flat racing jockeys have a lower incidence of falls (1 - 4 per 1,000 rides) than jumps racing jockeys (34 - 127 falls per 1,000 rides) due to the higher risks associated with jumps racing (Balendra et al., 2008; Forero Rueda et al., 2010; Hitchens et al., 2009; Legg et al., 2020b; O'Connor et al., 2017).

Table 1.1 Anthropometric characteristics (mean ± standard deviation) of jockeys and apprentices.

Reference	Country	Discipline	Experience	n	Gender	Age (yrs)	Height (m)	Weight (kg)	BMI (kg·m^{-2})
Cullen *et al.*, 2015	Ireland	Flat racing	Apprentice	12	Male	19 ± 2	1.72 ± 0.06	59.8 ± 4.7	20.3 ± 1.4
		Flat racing	Apprentice	10	Male	23 ± 3	1.65 ± 0.02	61.8 ± 5.6	22.7 ± 1.2
Dolan *et al.*, 2013	Ireland	Both	Professional	4 Flat, 5 Jumps	Male	24 ± 7	1.68 ± 0.05	58.2 ± 5.3	20.7 ± 1.7
Hitchens *et al.*, 2011	Australia	Both	Both	7 Flat, 1 Jumps	6 Male 2 Female	29 ± 10	1.63 ± 0.07	55.1 ± 5.9	20.6 ± 1.6
Jackson *et al.*, 2017	Great Britain	Flat racing	Apprentice	79	Male	19 ± 2	1.67 ± 0.06	52.9 ± 2.9	19.0 ± 1.4
		Jumps racing	Apprentice	69	Male	21 ± 2	1.76 ± 0.05	63.7 ± 3.6	20.6 ± 1.3
		Flat racing	Apprentice	37	Female	19 ± 2	1.57 ± 0.05	51.6 ± 4.0	20.8 ± 1.7
Jeon *et al.*, 2018	Korea	Flat racing	Professional	10	Male	32 ± 4	1.58 ± 0.05	50.6 ± 1.9	20.5 ± 1.4
Kiely *et al.*, 2019	Ireland	-	Trainee	11	Male	16 ± 1	1.67 ± 0.01	55.2 ± 6.1	19.9 ± 1.8
Leydon and Wall, 2002	NZ	Flat racing	Professional	9	4 Male 5 Female	29 ± 5	1.58 ± 0.05	51.3 ± 3.7	20.4 ± 1.6
			Apprentice	11	2 Male 9 Female	21 ± 4	1.58 ± 0.05	49.6 ± 3.3	20.0 ± 1.3
O'Reilly *et al.*, 2017	Hong Kong	Flat racing	Professional	20	Male	29 ± 8	1.62 ± 0.06	53.8 ± 3.3	20.5 ± 1.5
Press *et al.*, 1995	USA	-	Professional	706	614 Male 92 Female	31 ± 8	1.61 ± 0.07	50.4 ± 2.3	-
Quintana *et al.*, 2019	USA	Flat racing	Professional	15	Male	32 ± 10	1.61 ± 0.08	51.2 ± 1.5	-
Warrington *et al.*, 2009	Ireland	Flat racing	Professional	17	Male	27 ± 8	1.60 ± 0.10	53.1 ± 4.1	19.9 ± 1.3
		Jumps racing	Professional	10	Male	28 ± 5	1.73 ± 0.10	66.2 ± 2.9	22.1 ± 0.8
Wilson *et al.*, 2015	Great Britain	Flat racing	Professional	8	Male	26 ± 5	1.67 ± 0.04	57.0 ± 2.1	-
		Flat racing	Professional	8	Female	29 ± 8	1.63 ± 0.05	57.3 ± 3.5	-
Jockey Weighted Average		**Flat and Jumps racing**	**Professional and apprentice**	**1049**	**85% Male**	**28 ± 5**	**1.63 ± 0.05**	**52 ± 4**	**20.2 ± 0.9**
Population norms									
Pheasant and Haslegrave, 2006	Great Britain	Nationwide survey of British population in the year 2000		Estimate	5th percentile Male	19 - 65	1.63	55	20.8
				Estimate	20th percentile Female	19 – 65	1.56	53	21.6
Arriaza *et al.*, 2016	Chile	Senior rhythmic gymnasts		21	Female	16 – 19	1.61 (1.58 - 1.64)	52 (49 – 55)	20.1 (19.3 – 20.9)

1.5 Workload of jockeys

1.5.1 Workload constraints

Jockeys have the unique demand placed on them to remain in peak physical condition (Cullen *et al.*, 2015) and concurrently to maintain a strict and often unrealistic weight, on a daily basis, with no off-season (Wilson *et al.*, 2014). Jockeys must comply with the weight allocation of each horse they ride, with minimum riding weights of approximately 50 kg for flat jockeys worldwide (Hitchens *et al.*, 2011; Press *et al.*, 1995; Wilson *et al.*, 2013). Difficulty 'making weight' has been reported by 55% of Irish jockeys (Kiely *et al.*, 2020a). Jockeys use various means to achieve their daily riding weight, including restriction of daily fluid and nutritional intake, exercise, sauna use and use of diuretics and laxatives (Leydon and Wall, 2002; Wilson *et al.*, 2014). It is commonly reported that even mild dehydration (< 2%) can increase heart rate, hasten fatigue, and reduce exercise performance (O'Reilly *et al.*, 2017). In other weight category sports such as judo and boxing, rapid weight loss strategies are associated with impaired performance and negative mood states (Filaire *et al.*, 2001; Hall and Lane, 2001). This is no different for jockeys who have been shown to have reduced aerobic work capacity, strength, and simulated riding performance after a rapid reduction in body mass (both 2% reduction in 45 minutes, and 4% reduction over 48 hours) (Dolan *et al.*, 2013; Wilson *et al.*, 2014). As dehydration and reduced diet are common strategies used by jockeys to 'meet weight', there is a necessity for jockeys to have a strong basal fitness level.

A typical working week for a jockey or apprentice may vary considerably depending on their status and racing jurisdiction. However, the racehorses they ride require daily training at a canter or gallop as the primary method to condition the horse for racing. A typical working day for an apprentice or junior jockey usually involves riding morning exercise work for their local racehorse trainer, normally 5 – 6 days a week (Leydon and Wall, 2002). Additional workday activities of a junior jockey or apprentice, often up to 20 – 35 hours each week (Kiely *et al.*, 2020a; Leydon and Wall, 2002), may include activities relating to the care of the horse such as mucking out, grooming horses and carrying buckets of feed and water (Kiely *et al.*, 2019; Leydon and Wall, 2002). Top professional jockeys often spend considerable amounts of time travelling to races across the country and abroad (Vamplew, 2016). Working in addition to sports training is not usual practice for professional athletes where a large emphasis is placed on specificity and balancing the stressors of the sport with appropriate recovery to maximise performance in addition to minimizing injury risk (Kellmann, 2010).

Jockeys rarely participate in additional off-horse physical training except as a measure to reduce weight (Dolan *et al.*, 2011; Kiely *et al.*, 2020a; Leydon and Wall, 2002). Workday activities, though horse-centric, may be viewed by the jockey as sufficient physical preparation for race riding. Self-reported fatigue is prevalent among the jockey population and a substantial proportion of the jockey population is thought to remain in a state of chronic energy deficiency due to restricted food intake required to meet weight riding requirements (Dolan *et al.*, 2011). In addition to this, lack of quantification of sport specific and non-sport workload can result in a chronic imbalance in training stress and recovery which reduces athletic performance, resulting in fatigue lasting weeks to months, illness and injury (Halson, 2014). This is not surprising considering their total riding and working commitments in addition to their ubiquitous difficultly with weight management. Therefore, it is important that jockeys should participate in, or have access to a jockey specific fitness programme.

Many jockeys continue to ride after a fall, or with injuries they consider non-serious (including concussions), with one third of jockeys who have sustained injury not reporting it (Legg *et al.*, 2020b; O'Connor *et al.*, 2020a; O'Connor *et al.*, 2020b). Therefore, it is not unusual that a jockey may be riding whilst in pain, or compensating for previous injuries, which is likely to affect their riding performance. Knowledge of and access to effective off-horse rehabilitation and training for these jockeys may help to reduce risk posed to jockeys by riding with pain and injury.

1.5.2 External workload

Professional jockeys in Australasia and Ireland, ride in 1 - 8 races a day, over 2 - 4 race days a week, with no off-season (Dolan *et al.*, 2011; Legg *et al.*, 2020a; Leydon and Wall, 2002). In the United Kingdom (UK) and United States of America (USA) a jockeys' workload can be even higher, with races occurring up to 7 days a week (Press *et al.*, 1995; Warrington *et al.*, 2009). Jockeys in Ireland rode an average of 6.9 ± 6.4 races per week, with professional flat jockeys riding more often (16.3 ± 8.7 races per week, $p < 0.05$) than apprentices (5.9 ± 2.9 races per week) or jumps jockeys (5.4 ± 3.0 races per week) (Kiely *et al.*, 2020a). There is a large disparity between the number of rides of the top 10 - 20% of jockeys who are responsible for 70 - 80% of the total number of race-day rides ridden in a racing season (Legg *et al.*, 2020a). This indicates that there are a large number of jockeys who compete in few races. These jockeys have been found to be less successful and more likely to fall (and thus sustain injury) during a race than jockeys who ride in a higher number of races per season, which may be due to lack of 'race-day specific' conditioning and experience (skill) (Legg *et al.*, 2020a).

To date, the only external workload information for jockeys has been obtained by determining the number of races ridden by a jockey per race day or season (Cullen *et al.*, 2015; Dolan *et al.*, 2011; Legg *et al.*, 2020a; Leydon and Wall, 2002; Trowbridge *et al.*, 1995; Warrington *et al.*, 2009). However, these data can be misleading as it makes no differentiation between variables such as race length, competition level or nature of the horse, all of which influence the jockey's metabolic workload. Collection of such data could provide a workload index analogous to the TRIMP (training impulse) concept (Foster *et al.*, 2001). The advantage of such quantification of workload has been demonstrated with cyclists in long distance cycling events such as the Tour de France or Vuelta a España, who experience significantly different metabolic workloads depending on the comparative amounts of ascent and descent during a racing stage (Padilla *et al.*, 2001).

1.5.3 Internal workload

The exercise intensity of jockeys riding in a race is close to their maximal physiological capacity (Cullen *et al.*, 2015; O'Reilly *et al.*, 2017; Trowbridge *et al.*, 1995; Wilson *et al.*, 2013). Thus, they need high levels of aerobic and anaerobic power to be successful. Professional Irish jockeys in the 1970s were reported to be in better physical condition than professional football, baseball, basketball and hockey players in terms of cardiovascular endurance, upper and lower-body strength, and flexibility (Press *et al.*, 1995). Supporting evidence for the need for cardiovascular fitness was reported in the finding of Hitchens *et al.* (2011) that demonstrated that jockeys and trackwork riders with lower anaerobic and aerobic fitness were associated with a greater risk of falls and thus injury.

The maximal oxygen uptake ($\dot{V}O_{2max}$) of jockeys from Europe, Australia and Hong Kong ranged from 46 - 57 $mL \cdot kg^{-1} \cdot min^{-1}$, with peak heart rates in maximal aerobic capacity tests reaching 176 – 189 bpm (Cullen *et al.*, 2015; Dolan *et al.*, 2013; Hitchens *et al.*, 2011; Kiely *et al.*, 2019; O'Reilly *et al.*, 2017). These values indicate that jockeys have similar cardiorespiratory capacity to values reported for professional football, soccer and tennis players (49 - 58 $mL \cdot kg^{-1} \cdot min^{-1}$) (Franklin *et al.*, 1997).

Jockeys riding in competitive flat races have mean heart rates (HR) of 90 - 98% maximal, and respiration rates of 50 ± 7 breaths per minute (Cullen *et al.*, 2015; O'Reilly *et al.*, 2017). Mean HR for the duration of a national hunt (jumps) race reaches 80 – 94% of maximal (Kiely *et al.*, 2020b; Trowbridge *et al.*, 1995), with no significant period of recovery (to resting levels) between races (Trowbridge *et al.*, 1995). Jockey physiological demands differ according to distance and race type, with lower mean HR (79 ± 11% of maximal) observed in longer distance flat races (> 2,000 m vs 1,200 m) and higher rates of perceived exertion (RPE) observed in longer jumps races (Kiely *et al.*, 2020b). This suggests that during a race day, jockeys experience intermittent periods of intense cardiovascular load amongst sustained periods of elevated heart rate, which is similar to that experienced by cyclists in a semi mountainous stage of a long-distance cycling race (Padilla *et al.*, 2001).

A preliminary study characterising anaerobic characteristics of jockeys with the 30 second maximal effort cycle test suggest that jockeys have higher mean anaerobic power (9.57 ± 0.82 $W{\cdot}kg^{-1}$) than other equestrian riders (5.2 - 7.4 $W{\cdot}kg^{-1}$) (Hitchens *et al.*, 2011; Meyers, 2006) and national level team sports players (8.0 – 8.9 $W{\cdot}kg^{-1}$), assessed with the Wingate anaerobic power test (Kalinski *et al.*, 2002). This higher mean anaerobic power is probably due to the crouched quasi-isometric stance of the jockey on the horse requiring sustained muscle contractions resulting in high anaerobic metabolic requirements.

1.6 Muscle recruitment

The majority of studies on rider muscle activation and recruitment have focused on sports and recreation riders (Fortier Guillaume *et al.*, 2019; Gonzalez and Sarabon, 2020; Terada, 2000; Terada *et al.*, 2004), from which some parallels can be drawn. In contrast to the jockey position, characterised by an unseated crouching posture, English riders are seated on the horse. This 'seated' or 'three-point' position involves weight bearing predominantly through the pelvis, whilst the 'two-point' and 'jockey position' necessitates weight bearing to be through the rider's legs.

In English riding, both upper- and lower-body muscles contribute to rider performance in different gaits and over jumps (Fortier Guillaume *et al.*, 2019; Terada, 2000; Terada *et al.*, 2004). Upper-body muscles have been found to be important for stabilization and control of the riders' upper body and coordination during movements (Terada, 2000). Back muscles (*iliocostalis, teres major, extensor carpi ulnaris* and *serratus anterior muscles, erector spinae*) are thought to contribute to posture maintenance and stabilisation of the riders' core (Fortier Guillaume *et al.*, 2019; Terada, 2000). The *upper* and *middle trapezius, middle deltoid* and *flexor carpi radialis* stabilise the riders' neck, scapula and wrist during impact of the horse's stride (Terada *et al.*, 2004). A horse that pulls purportedly places increased strain on the riders' scapula stabilisers, as well as their thoracic and cervical spine (Pugh and Bolin, 2004). Lower-body muscles (*biceps femoris, gluteus maximus, gastrocnemius, rectus femoris*) are reported to contribute to both the stabilization and coordination of the rider over jumps (Fortier Guillaume *et al.*, 2019). Strength in the legs, lower back and arms are thought to be important for jumping and faster gaits, where the 'forward' or 'two-point' position (similar to the jockey position) is adopted (Roberts *et al.*, 2010). This position moves their center of mass (COM) anteriorly, causing riders to fatigue more quickly (Douglas *et al.*, 2012).

Assessment of surface electromyography (EMG) activity from select muscle groups in the upper body of English riders implies the need for muscular endurance due to long periods spent with muscles in tonic contraction to maintain posture (Douglas *et al.*, 2012; Terada *et al.*, 2004). As a horse progresses through the gaits (walk, trot, canter), the riders HR and oxygen consumption increases (Devienne and Guezennec, 2000; Kiely *et al.*, 2019) due to higher levels of tonic muscular contraction particularly of the trunk (Douglas *et al.*, 2012). This controlled trunk muscle contraction would be particularly important in jockeys who train and compete at the faster gaits (canter, gallop). In sports, neuromuscular fatigue has a direct impact on athletic performance (Bourdon *et al.*, 2017; Enoka and Duchateau, 2008) and cognitive performance (Moore *et al.*, 2012). This may have implications for jockeys coping with the high technical skills of riding and the necessary split-second decision making to ensure a horse runs to its full potential in the safest possible environment.

An equestrian's muscular fitness (strength and endurance) is important for not only controlling their own position, but also for controlling the horse (Terada *et al.*, 2004). This requires sustained upper body strength in combination with maintenance of trunk postural stability and can vary according to the nature of the horse ridden. Unlike most equestrian sports, a jockey and horse do not necessarily train together, with a jockey able to obtain a competitive ride on a horse they may have never ridden before. In both English riders and jockeys, oxygen consumption and HR has been shown to vary according to the nature of the horse being ridden (Devienne and Guezennec, 2000; Kiely *et al.*, 2019; Roberts *et al.*, 2010). Specifically, a lethargic horse may require additional pushing and a nervous horse may require extra restraint on the part of the jockey. In addition, riding an unknown horse at canter has been shown to increase the energy expenditure of the rider (Devienne and Guezennec, 2000). This further increases the need for a strong basal fitness level for a jockey to prepare for the added pressure of riding an unfamiliar horse.

1.7 Horse and rider synchronicity

Expertise in any sport is characterised with an optimally adapted posture with specific coordination patterns (Baillet *et al.*, 2017) and is highly dependent on the nature of the activity. Experts in any sport have better movement control and stability, and therefore more efficient movement (Sparrow, 1983). In horse riding, isometric contractions of core trunk muscles are used by riders to stabilize their positions whilst accommodating propulsive forces from the horse (Terada, 2000; Terada *et al.*, 2004). Adapting and learning to predict the movements of the horse can lead to more coordinated movement of the rider, facilitated by the synchronized contractions of the *rectus abdominis* and *erector spinae* muscles stabilizing the riders' trunk (core muscles) (Pantall *et al.*, 2009; Terada, 2000; Terada *et al.*, 2004). Novice riders demonstrate a failure to maintain the ideal trunk position with less active control of their posture than experienced riders (Eckardt and Witte, 2016; Terada, 2000; Terada *et al.*, 2004), in part due to an inability to contract the core muscles appropriately (Gonzalez and Sarabon, 2020; Pantall *et al.*, 2009). Novice riders additionally recruit *adductor magnus* muscles in an attempt to maintain balance, reducing their synchronicity with the horse (Terada, 2000).

Advanced riders have a higher ability to anticipate horse movement at a neuromuscular level with more defined and relaxed contralateral muscular activation patterns than novice riders (Gonzalez and Sarabon, 2020). The more coordinated muscle contraction and independence of movement of expert riders results in a tighter phase relationship with the horse and distinguishes them from novice riders (Baillet *et al.*, 2017; Bystrom *et al.*, 2009; Gonzalez and Sarabon, 2020; Lagarde *et al.*, 2005; Terada, 2000). Additionally, greater rider stability and synchronisation has been associated with a lower injury risk both to the horse and rider (due to a lower likelihood both from falling and of muscular overuse/misuse) than riders with poor synchronicity (Bystrom *et al.*, 2009; Wilkins *et al.*, 2020). The lack of synchronicity results in greater energy expenditure by novice riders when completing the same exercises as a skilled rider (Hobbs *et al.*, 2020).

Muscular activation patterns can be improved through specific exercises (Asaka *et al.*, 2008). This may be an important consideration for apprentice jockeys as a method to increase jockey-horse synchronicity by both reducing the training load on the horse and the time spent at risk of falling for the jockey. Galloping gaits are associated with more accidents, involve higher velocity and the biomechanics of the gait dictate that the rider feels forces in the medial/lateral and fore/aft directions (Lagarde *et al.*, 2005). This effect is exacerbated in jockeys who ride predominantly galloping gaits in an unseated posture. Development of a measurement system to quantify jockey stability could be an invaluable tool in assessing the skill and preparation of jockeys to compete safely.

1.7.1 Performance measures

Movement of the jockeys' head plays a key role in maintaining the correct posture in horse riding. Less skilled dressage riders have been observed to have more head movement than skilled riders (Eckardt and Witte, 2016; Terada, 2000). A steady head position enables optimal performance of the central nervous system (CNS), and is important to maintain optimal visual acuity, vestibular signals, and decision-making processes (Newell and Mansfield, 2008; Pozzo *et al.*, 1995). Cross-country mountain bikers have been found to limit the transference of external vibration/movement of the bike via muscular work to maintain a steady head position (Macdermid *et al.*, 2014). However, the muscular work and postural changes required to damp equine movement to reduce jockey head movement has not been investigated. Fatiguing muscles may be compensated for by postural changes which recruit different muscles, prolonging the ability to maintain a position (Boyas and Guevel, 2011; Enoka and Duchateau, 2008). This may have a large effect on the ability of a jockey to maintain synchronicity with the horse and may lead to more pronounced head movements on the part of the jockey. Maintenance of a steady head position to enable optimal CNS function is essential for jockeys to negotiate the high-speed technicalities of race riding and may be an important tool in assessing the skill level of the jockey. However, it is important to account for differences in individual riding strategies when assessing skill levels (Wilkins *et al.*, 2020).

Accelerometers have measured the differences in acceleration and displacement of horse and jockey (Pfau *et al.*, 2009; Walker *et al.*, 2016). The jockey's body has been found to move little with respect to the world inertial frame but overcompensates for the horses' motion in a fore/aft direction (Pfau *et al.*, 2009). Many sports have been successful in using these devices to quantify the common biomechanical loads athletes are routinely exposed to (Bourdon *et al.*, 2017), and to determine the damping effects of muscles to stabilise the body against external mechanical forces of locomotion (Macdermid *et al.*, 2014). Defining the optimal movement kinematics for a jockey will not only aid in understanding the demands during racing but will help in developing a protocol to aid in training apprentice jockeys or assist the return to riding of an injured jockey.

1.8 Physical conditioning

For the majority of horse riders, the primary method of training is through riding itself (Pugh and Bolin, 2004; Roberts *et al.*, 2010), and this is no different for jockeys (Kiely *et al.*, 2020a). This approach is not recommended in other sports due to the potential for overtraining, particularly in highly competitive sporting environments (Meyers and Sterling, 2000).

However, the daily riding work of jockeys has been suggested to be insufficient to meet the physiological demands of racing, highlighting the importance of performing supplementary sport specific training (Kiely *et al.*, 2019). It has been often suggested that additional un-mounted training may benefit ridden performance in English riders (Devienne and Guezennec, 2000; Douglas *et al.*, 2012; Kiely *et al.*, 2019; Pugh and Bolin, 2004), but there is a paucity of evidence clarifying the sport specific effects of this.

An isometric strength training programme, targeting core muscles (*rectus abdominis*, *erector spinae* and hip adductors) has been shown to improve muscular strength and endurance and ridden dressage scores in a small group (n = 18) of dressage riders (Lee *et al.*, 2015). A core fitness programme involving core strengthening and hip stability exercises has also demonstrated improved rider symmetry in a small number (n = 10) of dressage riders (Hampson and Randle, 2015). More advanced riders have better core strength and muscle tone than less advanced riders, and in comparison to age and gender matched non-elite athletes in other sports (Gonzalez and Sarabon, 2020; Meyers and Sterling, 2000). However, to date there are no published data on core muscle recruitment and asymmetry in jockeys or apprentice riders.

In preparing jockeys to meet the demands of racing, a greater aerobic capacity may reduce the risk of falls and resulting injury (Hitchens *et al.*, 2010). This may also result in jockeys experiencing faster recovery rates by reducing fatigue between races. More skilled jockeys are known to be at a lower risk of falling (Hitchens *et al.*, 2012; Legg *et al.*, 2020b), however skill comes with repeated training over time. Therefore, methods to improve race jockey technique and skill off horse (thus less risk) are important to improve both horse and jockey welfare and reduce their risk of falling.

1.9 Conclusions

The current understanding of the physiological demands, muscle activity and synchronicity of movement of race riding has been drawn from research with relatively small samples within a range of equestrian disciplines. Jockeys work at close to their physiological capacity during a race. The jockey position requires great muscular strength and endurance in the jockey's legs and core to both maintain their position and adapt to the movement of the horse. More synchronous movement between horse and rider involves a more coordinated activation pattern of the rider's core muscles, resulting in less work done by the horse to carry the rider. A lack of information on jockey specific fitness and fitness regimes are notable limitations in the scientific literature. Further physiological and workload data specific to jockeys are required to understand the specific demands of the sport. These data could lead to the development of evidence-based sport specific and potentially performance enhancing rider strength and conditioning programmes.

1.10 References

Arriaza, E., Rodríguez, C., Carrasco, C., Mardones, C., Niedmann, L. and López-Fuenzalida, A. (2016). Anthropometric characteristics of elite rhythmic gymnasts. *International Journal of Morphology,* 34(1): 17-22. doi: https://doi.org/10.4067/s0717-95022016000100003

Asaka, T., Wang, Y., Fukushima, J. and Latash, M.L. (2008). Learning effects on muscle modes and multi-mode postural synergies. *Experimental Brain Research,* 184(3): 323-338. doi: https://doi.org/10.1007/s00221-007-1101-2

Baillet, H., Thouvarecq, R., Verin, E., Tourny, C., Benguigui, N., Komar, J. and Leroy, D. (2017). Human energy expenditure and postural coordination on the mechanical horse. *Journal of Motor Behaviour,* 49(4): 441-457. doi: https://doi.org/10.1080/00222895.2016.1241743

Balendra, G., Turner, M. and McCrory, P. (2008). Career-ending injuries to professional jockeys in British horse racing (1991-2005). *British Journal of Sports Medicine,* 42(1): 22-24. doi: https://doi.org/10.1136/bjsm.2007.038950

Bolwell, C.F., Rogers, C.W., Gee, E.K. and Rosanowski, S.M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science*, 56(1): 77- 81. doi: https://doi.org/10.1071/an13442

Bourdon, P.C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M.C., Gabbett, T.J., Coutts, A.J., Burgess, D.J., Gregson, W. and Cable, N.T. (2017). Monitoring athlete training loads: consensus statement. *International Journal of Sports Physiology and Performance,* 12(Suppl 2): S2161-S2170. doi: https://doi.org/10.1123/IJSPP.2017-0208

Boyas, S. and Guevel, A. (2011). Neuromuscular fatigue in healthy muscle: underlying factors and adaptation mechanisms. *Annals of Physical and Rehabilitation Medicine*, 54(2): 88-108. doi: https://doi.org/10.1016/j.rehab.2011.01.001

Bystrom, A., Rhodin, M., von Peinen, K., Weishaupt, M.A. and Roepstorff, L. (2009). Basic kinematics of the saddle and rider in high-level dressage horses trotting on a treadmill. *Equine Veterinary Journal,* 41(3): 280-284. doi: https://doi.org/10.2746/042516409x394454

Cullen, S.J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G. and Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Curry, B.A., Hitchens, P.L., Otahal, P., Si, L. and Palmer, A.J. (2016). Australian insurance costs of jockeys injured in a race-day fall. *Occupational Medicine,* 66(3): 222-229. doi: https://doi.org/10.1093/occmed/kqv150

Devienne, M.-F. and Guezennec, C.-Y. (2000). Energy Expenditure of horse riding. *European Journal of Applied Physiology,* 82(5/6): 499-503. doi: https://doi.org/10.1007/s004210000207

Dolan, E., Cullen, S.J., McGoldrick, A. and Warrington, G.D. (2013). The impact of making weight on physiological and cognitive processes in elite jockeys. *International Journal of Sport Nutrition and Exercise Metabolism,* 23: 399 -408.

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D. and Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Science,* 29(8): 791-799. doi: https://doi.org/10.1080/02640414.2011.560173

Douglas, J.L., Price, M. and Peters, D.M. (2012). A systematic review of physical fitness, physiological demands and biomechanical performance in equestrian athletes. *Comparative Exercise Physiology,* 8(1): 53-62. doi: https://doi.org/10.3920/cep12003

Eckardt, F. and Witte, K. (2016). Kinematic Analysis of the Rider According to Different Skill Levels in Sitting Trot and Canter. *Journal of Equine Veterinary Science,* 39: 51-57. doi: https://doi.org/10.1016/j.jevs.2015.07.022

Enoka, R.M. and Duchateau, J. (2008). Muscle fatigue: what, why and how it influences muscle function. *Journal of Physiology,* 586(1): 11-23. doi: https://doi.org/10.1113/jphysiol.2007.139477

Filaire, E., Maso, F., Degoutte, F., Jouanel, P. and G.Lac (2001). Food restriction, performance, psychological state and lipid values in judo athletes. *International Journal of Sports Medicine,* 22: 454 - 459.

Forero Rueda, M.A., Halley, W.L. and Gilchrist, M.D. (2010). Fall and injury incidence rates of jockeys while racing in Ireland, France and Britain. *Injury,* 41(5): 533-539. doi: https://doi.org/10.1016/j.injury.2009.05.009

Fortier Guillaume, J., Laroche, D. and Babault, N. (2019). Kinematics and electromyographic activity of horse riders during various cross-country jumps in equestrian. *Sports Biomechanics,* 20(6): 680-692. doi: https://doi.org/10.1080/14763141.2019.1597154

Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., Doleshal, P. and Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research,* 15(1): 109 - 115. doi: https://doi.org/10.1519/00124278-200102000-00019

Franklin, B.A., Fletcher, G.F., Gordon, N.F., Noakes, T.D., Ades, P.A. and Balady, G.J. (1997). Cardiovascular evaluation of the athlete. *Sports Medicine,* 24(2): 97-119. doi: https://doi.org/12-1642/97/0008-0097

Gonzalez, M.E. and Sarabon, N. (2020). Muscle modes of the equestrian rider at walk, rising trot and canter. *Plos One*, 15(8): e0237727. doi: https://doi.org/10.1371/journal.pone.0237727

Hall, C.J. and Lane, A.M. (2001). Effects of rapid weight loss on mood and performance among amateur boxers. *British Journal of Sports Medicine,* 35: 390 - 395.

Halson, S.L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine,* 44 (Suppl 2): S139-147. doi: https://doi.org/10.1007/s40279-014-0253-z

Hampson, A. and Randle, H. (2015). The influence of an 8-week rider core fitness program on the equine back at sitting trot. *International Journal of Performance Analysis in Sport,* 15(3): 1145-1159. doi: https://doi.org/10.1080/24748668.2015.11868858

Hitchens, P., Blizzard, L., Jones, G., Day, L. and Fell, J. (2011). Are physiological attributes of jockeys predictors of falls? A pilot study. *British Medical Journal Open,* 1(1): e000142. doi: https://doi.org/10.1136/bmjopen-2011-000142

Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L. and Fell, J. (2010). Predictors of race-day jockey falls in flat racing in Australia. *Occupational and Environmental Medicine,* 67(10): 693-698. doi: https://doi.org/10.1136/oem.2009.050567

Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L.M. and Fell, J. (2009). The incidence of race-day jockey falls in Australia, 2002–2006. *The Medical Journal of Australia,* 190(2): 83-86. doi: https://doi.org/10.5694/j.1326-5377.2009.tb02284.x

Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L.M. and Fell, J. (2012). The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention,* 18(6): 385-391. doi: https://doi.org/10.1136/injuryprev-2011-040255

Hobbs, S.J., St George, L., Reed, J., Stockley, R., Thetford, C., Sinclair, J., Williams, J., Nankervis, K. and Clayton, H.M. (2020). A scoping review of determinants of performance in dressage. *PeerJ,* 8: e9022. doi: https://doi.org/10.7717/peerj.9022

Jackson, K.A., Sanchez-Santos, M.T., MacKinnon, A.L., Turner, A., Kuznik, K., Ellis, S., Box, C., Hill, J., Javaid, M.K., Cooper, C., Arden, N.K. and Newton, J.L. (2017). Bone density and body composition in newly licenced professional jockeys. *Osteoporosis International,* 28(9): 2675-2682. doi: https://doi.org/10.1007/s00198-017-4086-0

Jeon, S., Cho, K., Ok, G., Lee, S. and Park, H. (2018). Weight loss practice, nutritional status, bone health, and injury history: A profile of professional jockeys in Korea. *Journal of Exercise Nutrition and Biochemistry,* 22(3): 27-34. doi: https://doi.org/10.20463/jenb.2018.0021

Kalinski, M., Norkowski, H., Kerner, M. and Tkaczuk, W. (2002). Anaerobic power characteristics of elite athletes in national level team-sport games. *European Journal of Sport Science,* 2(3): 1-21. doi: https://doi.org/10.1080/17461390200072303

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicine and Science in Sports,* 20(Suppl 2): 95-102. doi: https://doi.org/10.1111/j.1600-0838.2010.01192.x

Kiely, M., Warrington, G., McGoldrick, A. and Cullen, S.J. (2020a). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi: https://doi.org/10.1519/JSC.0000000000003514. Epub ahead of print.

Kiely, M., Warrington, G.D., McGoldrick, A., Pugh, J. and Cullen, S. (2020b). Physiological demands of professional flat and jump horse racing. *Journal of Strength and Conditioning Research,* 34(8): 2173-2177.

Kiely, M.A., Warrington, G.D., McGoldrick, A., O'Loughlin, G. and Cullen, S. (2019). Physiological demands of daily riding gaits in jockeys. *Journal of Sports Medicine and Physical Fitness,* 59(3): 394-398. doi: https://doi.org/10.23736/S0022-4707.18.08196-3

Lagarde, J., Kelso, J.A., Peham, C. and Licka, T. (2005). Coordination dynamics of the horse-rider system. *Journal of Motor Behaviour,* 37(6): 418–424.

Landolt, K., Maruff, P., Horan, B., Kingsley, M., Kinsella, G., O'Halloran, P.D., Hale, M.W. and Wright, B.J. (2017). Chronic work stress and decreased vagal tone impairs decision making and reaction time in jockeys. *Psychoneuroendocrinology,* 84: 151-158. doi: https://doi.org/10.1016/j.psyneuen.2017.07.238

Lee, J.T., Soboleswki, E.J., Story, C.E., Shields, E.W. and Battaglini, C.L. (2015). The feasibility of an 8-week, home-based isometric strength-training program for improving dressage test performance in equestrian athletes. *Comparative Exercise Physiology,* 11(4): 223-230. doi: https://doi.org/10.3920/cep150018

Legg, K., Cochrane, D., Gee, E. and Rogers, C. (2020a). The external workload of Thoroughbred horse racing jockeys *Sustainability,* 12 (18). doi: https://doi.org/10.3390/su12187572

Legg, K.A., Cochrane, D.J., Bolwell, C.F., Gee, E.K. and Rogers, C.W. (2020b). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport,* 23: 1154-1160. doi: https://doi.org/10.1016/j.jsams.2020.05.015

Leydon, M.A. and Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12: 220-237.

Macdermid, P.W., Fink, P.W. and Stannard, S.R. (2014). Transference of 3D accelerations during cross country mountain biking. *Journal of Biomechanics,* 47(8): 1829-1837. doi: https://doi.org/10.1016/j.jbiomech.2014.03.024

Mayberry, J.C., Pearson, T.E., Wiger, K.J., Diggs, B.S. and Mullins, R.J. (2007). Equestrian injury prevention efforts need more attention to novice riders. *Journal of Trauma*, 62(3): 735-739. doi: https://doi.org/10.1097/ta.0b013e318031b5d4

Meyers, M.C. (2006. Effect of equitation training on health and physical fitness of college females. *European Journal of Applied Physiology,* 98(2): 177-184. doi: https://doi.org/10.1007/s00421-006-0258-x

Meyers, M.C. and Sterling, J.C. (2000. Physical, hematological, and exercise response of collegiate female equestrian athletes. *Journal of Sports Medicine and Physical Fitness,* 40: 131-138.

Moore, R.D., Romine, M.W., O'Connor P, J. and Tomporowski, P.D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Science,* 30(9): 841-850. doi: https://doi.org/10.1080/02640414.2012.675083

Newell, G.S. and Mansfield, N.J. (2008. Evaluation of reaction time performance and subjective workload during whole-body vibration exposure while seated in upright and twisted postures with and without armrests. *International Journal of Industrial Ergonomics,* 38(5-6): 499-508. doi: https://doi.org/10.1016/j.ergon.2007.08.018

O'Connor, S., Warrington, G., McGoldrick, A. and Cullen, S. (2018). A 9-year epidemiologic study (2007-2015) on race-day jockey fall and injury incidence in amateur Irish horse racing. *Journal of Athletic Training,* 53(10): 950-955.

O'Connor, S., Warrington, G., McGoldrick, A. and Cullen, S.J. (2017). Epidemiology of injury due to race-day jockey falls in professional flat and jump horse racing in Ireland, 2011-2015. *Journal of Athletic Training,* 52(12): 1140-1146. doi: https://doi.org/10.4085/1062-6050-52.12.17

O'Connor, S., Warrington, G., Whelan, G., McGoldrick, A. and Cullen, S. (2020a). Concussion history, reporting behaviors, attitudes, and knowledge in jockeys. *Clinical Journal of Sport Medicine,* 30(6): 578-584. doi: 10.1097/JSM.0000000000000658

O’Connor, S., Warrington, G., O’Brien, S., McDermott, E., McGoldrick, A., Pugh, J. and Cullen, S. (2020b). Injuries outside of horseracing: is it time to focus on injury prevention of jockeys outside of races? *The Physician and Sportsmedicine,* 49(1): 45-50. doi: https://doi.org/10.1080/00913847.2020.1760693

O'Reilly, J., Cheng, H.L. and Poon, E.T.-C. (2017). New insights in professional horse racing; "in-race" heart rate data, elevated fracture risk, hydration, nutritional and lifestyle analysis of elite professional jockeys. *Journal of Sports Science,* 35(5): 441-448. doi: https://doi.org/10.1080/02640414.2016.1171890

Padilla, S., Mujika, I., Orbananos, J., Santisteban, J., Angulo, F. and Goiriena, J. (2001). Exercise intensity and load during mass-startstage races in professional road cycling. *Medicine and Science in Sports and Exercise,* 33: 796–802.

Pantall, A., Barton, S. and Collins, P. (2009). *Surface electromyography of abdominal and spinal muscles in adult horseriders during rising trot*, Paper presented at the 27th International Conference on Biomechanics in Sports, Limerick, Ireland.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004). Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal,* 36(6): 521-526.

Peham, C., Kotschwar, A.B., Borkenhagen, B., Kuhnke, S., Molsner, J. and Baltacis, A. (2010). A comparison of forces acting on the horse's back and the stability of the rider's seat in different positions at the trot. *Veterinary Journal,* 184(1): 56-59. doi: https://doi.org/10.1016/j.tvjl.2009.04.007

Pfau, T., Spence, A., Starke, S., Ferrari, M. and Wilson, A. (2009). Modern riding style improves horse racing times. *Science,* 325(5938): 289. doi: https://doi.org/10.1126/science.1174605

Pheasant, S. and Haslegrave, C., M. (2006). *Bodyspace: Anthropometry, ergonomics and the design of work (3rd ed).* FL, USA:Taylor and Francis Group

Pozzo, T., Levik, Y. and Berthoz, A. (1995). Head and trunk movements in the frontal plane during complex dynamic equilibrium tasks in humans. *Experimental Brain Research,* 106(2): 327–338.

Press, J.M., Davis, P.D., Wiesner, S.L., Heinemann, A., Semik, P. and Addison, R.G. (1995). The national jockey injury study: an analysis of injuries to professional horse-racing jockeys. *Clinical Journal of Sport Medicine,* 5(4): 236-240.

Proudman, C., Pinchbeck, G., Clegg, P. and French, N. (2004). Risk of horses falling in the Grand National. *Nature,* 428(6981): 385-386. doi: https://doi.org/10.1038/nature02481

Pugh, T.J. and Bolin, D. (2004). Overuse injuries in equestrian athletes. *Current Sports Medicine Reports,* 3(6): 297-303.

Quintana, C., Grimshaw, B., Rockwood, H.E., Heebner, N.J., Johnson, A.K., Ryan, K.D. and Mattacola, C.G. (2019). Differences in head accelerations and physiological demand between live and simulated professional horse racing. *Comparative Exercise Physiology,* 15(4): 259-268. doi: https://doi.org/10.3920/cep190005

Roberts, M., Shearman, J. and Marlin, D. (2010). A comparison of the metabolic cost of the three phases of the one-day event in female collegiate riders. *Comparative Exercise Physiology,* 6(3): 129-135. doi: https://doi.org/10.1017/s1755254010000012

Sparrow, W.A. (1983). The efficiency of skilled performance. *Journal of Motor Behaviour,* 15(3): 237-261. doi: https://doi.org/10.1080/00222895.1983.10735299

Terada, K. (2000). Comparison of head movement and EMG activity of muscles between advanced and novice horseback riders at different gaits. *Journal of Equine Science,* 11(4): 83-90. doi: https://doi.org/10.1294/jes.11.83

Terada, K., Mullineaux, D.R., Lanovaz, J., Kato, K. and Clayton, H.M. (2004). Electromyographic activity of the rider's muscles at trot. *Equine and Comparative Exercise Physiology,* 1(3): 193-198. doi: https://doi.org/10.1079/ECEP200420

Trowbridge, E.A., Cotterill, J.V. and Crofts, C.E. (1995). The physical demands of riding in National Hunt races. *European Journal of Applied Physiology,* 70(1): 66-69.

Vamplew, W. (2016). Still crazy after all those years: continuity in a changing labour market for professional jockeys. *Sport in Society,* 19(3): 378-399. doi: https://doi.org/10.1080/17430437.2015.1059015

Walker, A.M., Applegate, C., Pfau, T., Sparkes, E.L., Wilson, A.M. and Witte, T.H. (2016). The kinematics and kinetics of riding a racehorse: A quantitative comparison of a training simulator and real horses. *Journal of Biomechanics,* 49(14): 3368-3374. doi: https://doi.org/10.1016/j.jbiomech.2016.08.031

Waller, A.E., Daniels, J.L., Weaver, N.L. and Robinson, P. (2001). Jockey injuries in the United States. *American Journal of Emergency Medicine,* 283: 1326 - 1328.

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M. and Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Science,* 27(6): 543-550. doi: https://doi.org/10.1080/02640410802702863

Wilkins, C.A., Nankervis, K., Protheroe, L. and Draper, S.B. (2020). Static pelvic posture is not related to dynamic pelvic tilt or competition level in dressage riders. *Sports Biomechanics*: 1-13. doi: https://doi.org/10.1080/14763141.2020.1797150

Wilson, G., Hawken, M.B., Poole, I., Sparks, A., Bennett, S., Drust, B., Morton, J. and Close, G.L. (2014). Rapid weight-loss impairs simulated riding performance and strength in jockeys: implications for making-weight. *Journal of Sports Science,* 32(4): 383-391. doi: https://doi.org/10.1080/02640414.2013.825732

Wilson, G., Hill, J., Sale, C., Morton, J.P. and Close, G.L. (2015). Elite male Flat jockeys display lower bone density and lower resting metabolic rate than their female counterparts: implications for athlete welfare. *Applied Physiology, Nutrition & Metabolism,* 40(12): 1318-1320.

Wilson, G., Sparks, S.A., Drust, B., Morton, J.P. and Close, G.L. (2013). Assessment of energy expenditure in elite jockeys during simulated race riding and a working day: implications for making weight. *Applied Physiology Nutrition and Metabolism,* 38(4): 415-420. doi: https://doi.org/10.1139/apnm-2012-0269

1.11 Epilogue to Chapter One

In the time since this review was published in 2021, there have been a small number of new articles which further support the research described in Chapter One. Both competition (race or jumping course) distance and inexperience of jockey and rider have been recognised as a risk factor for falls in Japanese horse racing and Fédération Équestre Internationale (FEI) eventing (Bennet *et al.*, 2021; Mizobe *et al.*, 2021), further supporting the supposition that physical conditioning and skill level of the jockey or rider is an important factor in competition safety. Additionally, physical fitness, specifically strength and endurance, was positively associated with riding performance in 115 non-elite Swiss equestrians from a range of equestrian disciplines (Aegerter *et al.*, 2020). In Australia, 89% of the, on average, 200 jockeys injured annually required medical attention, with 40% of these unable to ride for an average of 5 weeks after injury (Giusti Gestri, 2021), indicating that an off-horse jockey specific physical training programme would be beneficial for the reconditioning of these jockeys unable to ride. However, Ryan *et al.* (2021) confirmed that a jockey's usual exercise regime did not appear to benefit a rider's metabolism or comprise of sports specific conditioning, noting they may have only approximately 45 minutes of strenuous activity daily, much less than a professional athlete training for a different sport.

A number of new studies have further elucidated differences between rider synchrony and skill levels. More experienced riders have been reported to have greater hip extension and external rotation compared to novices when riding dressage movements in trot (Baxter *et al.*, 2022). Experienced riders activated their muscles earlier in the horses stride cycle than novices, effectively anticipating horse motion and thus achieving greater shock attenuation of the horses movement than novices (Gonzalez *et al.*, 2021). More experienced Olympic level

FEI riders had greater postural control in the anterior direction and posterolateral balance than less experienced FEI riders in off-horse physical tests, with greater symmetry between their left and right side strength and balance, suggesting that at high level competition, multiple movement qualities and optimisation of movement patterns are required (Demarie *et al.*, 2022). Male riders have been reported to have a more neutral position on the horse than female riders (with a posteriorly rotated pelvis), indicating they have a biomechanical advantage when riding in the English style (Bye *et al.*, 2022). However, individual rider differences in posture and timing of muscular activation patterns are reported to persist between riders, even when riding multiple horses (Egenvall *et al.*, 2022).

Although these studies were conducted with English riders, they confirm the observation that more advanced riders have a greater ability to anticipate and move in synchrony with the horse, mainly through anticipatory effective postural corrections to maintain a centred and stable position on the horse. Although pelvic movement may not be as important for jockeys who ‘crouch’ in their stirrups, isolating their COM from that of the horse, anticipatory muscular activation likely plays an important role in achieving synchronous movement with the horse, and thus improving performance and reducing injury risk to jockeys from falling from the horse.

2 Chapter Two - Incidence and risk factors for race-day jockey falls over fourteen years

Published in part in the following publication.

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport*, 23, 1154-1160. doi:10.1016/j.jsams.2020.05.015

2.1 Foreword to Chapter Two

The previous chapter demonstrated that jockeys compete in a high-risk sport, and exercise at close to maximum physiological capacity during a race. Consequently, unconditioned jockeys potentially experiencing fatigue may increase their risk of injury from poor performance or falling from the horse. Industry modification to increase jockey safety and reduce risk of falls begins with identifying risk factors. This has been successful in other sports (Beaudouin *et al.*, 2019; Longo *et al.*, 2012), with adjustments to training regimes the most common strategy to prevent injury in athletes, though changes in sporting regulations have been shown to have a greater effect on decreasing injury risk (Vriend *et al.*, 2017). As racing rules, regulations and training between jurisdictions vary, it is important to determine the specific risk factors and racing culture for a particular jurisdiction. Given the differences in muscular activation and posture between novice and experienced riders, it would be reasonable to assume that novice riders would be more at risk of falling off the horse during top level competitions. Indeed, jockey and horse experience have both been related to an increased risk of jockey falls during racing in Australia, Ireland and Japan (Hitchens *et al.*, 2011; Hitchens *et al.*, 2010; Mizobe *et al.*, 2021; O'Connor *et al.*, 2018), however, specific risk factors for jockey falls in New Zealand had not been previously investigated, and it was important to determine if similar risk factors were evident in jockeys in New Zealand. This would provide a starting point to understand jockey workload and highlight the importance that physical conditioning may have on the health and safety for jockeys. Therefore, the first step in this research was to examine the incidence and risk factors for race-day jockey falls in New Zealand.

2.2 Abstract

The objectives of this paper were to determine the incidence of, and risk factors for, race-day jockey falls occurring in Thoroughbred flat and jumps (hurdle and steeplechase) racing. A retrospective cohort study was used. Incidence rates for race-day jockey falls over 14 racing seasons in New Zealand (n = 421,596 race-day starts) were calculated per 1,000 rides. Univariable and multivariable analyses of jockey, horse and race level risk factors were conducted with Poisson regression in a generalized linear mixed model.

Most races (97%, n = 407,948 race starts) were flat racing with 10 races/race-day, whilst most jumps races were longer and had 2 races/race-day. The rate of jockey falls was higher in steeplechase racing (99.9/ 1,000, 95% CI 92.2 – 108.4) than hurdle (53.2/1,000, 95% CI 48.7 – 58.3) and flat racing (1.2/1,000, 95% CI 1.1 – 1.3, $p < 0.001$). Experienced athletes (both horse and jockey) had lower IRR. In flat racing, IRR increased linearly with the number of race-day rides by the jockey. In jumps races, IRR increased with a fall in a previous race (IRR 1.5/1,000, 95% CI 1. 3 - 1.7, $p < 0.001$). A shorter jumps race distance reduced the IRR of a jockey fall. Jockey experience was associated with risk of jockey falls. The linearity of race ride number with IRR and longer distance in jumps racing, indicated that cognitive or physiological fatigue may play a role in the risk of a race-day fall. These data highlight the role sport-specific conditioning programmes may have on reducing risk.

2.3 Introduction

Thoroughbred racing is a professional sport in which a jockey and horse work together, racing at speeds exceeding 60 $km \cdot h^{-1}$ (Warrington *et al.*, 2009). Jockeys are positioned over the horses' withers, in a crouched forward stance involving a continuous state of quasi-isometric movement. An unexpected movement from the horse can propel the jockey onto the ground from a height of 2 - 3 m (Turner *et al.*, 2002). There is little room for error during a race, and the consequence of a misjudgment could result in a fall or injury to either or both athletes.

Thoroughbred racing is divided into flat and jumps racing. In New Zealand, flat racing has a median distance of 1,400 m (interquartile range IQR 1,200 - 1,670 m) with no obstacles (Bolwell *et al.*, 2016). Jumps racing is longer (median distance of 3,100 m (IQR 2,900 - 4,000 m) (Bolwell *et al.*, 2016) and includes two separate events with different types of obstacle; hurdle (removable fences with maximum height of 1.2 m) and steeplechase fences which can be permanent or removable with a height of 1.5 m (New Zealand Thoroughbred Racing, 2019b). Jumps racing takes place in the winter season and has fewer races per year (median 122 vs 2,934 races) than flat races. Horses competing in jumps racing carry higher weights (mean 65 vs 56 kg), are older (IQR of 6 - 9 vs 3 - 5 years) and have a higher proportion of males (91% vs 54%) than horses in flat racing. Due to these differences, flat, hurdle and steeplechase racing were considered separately in this study.

The rates of jockey falls and the prevalence of injury reported differ between racing jurisdictions and between flat and jumps racing. The incidence of jockey falls in jumps racing are a magnitude greater than observed in flat racing; in Australia, Ireland, Britain and France, jumps racing fall rates are 34 – 127 per 1,000 rides whereas flat racing in Australia, Ireland and United States have rates of 1.9 - 4.4 per 1,000 rides (Balendra *et al.*, 2008; Forero Rueda *et al.*, 2010; Hitchens *et al.*, 2009; O'Connor *et al.*, 2017; Turner *et al.*, 2002). Although flat racing jockeys fall less often, they have a higher injury incidence (27 - 51%) than jumps racing jockeys (8 - 18%) (Balendra *et al.*, 2007; Curry *et al.*, 2016; Hitchens *et al.*, 2009; McCrory *et al.*, 2006; Turner *et al.*, 2002). This highlights the high-risk nature of the sport, with jockey injury incidences in jumps racing 1 - 4 times that of professional rugby players (91 injuries per 1,000 player hours) (Brooks *et al.*, 2005). Studies in Australia and Ireland have determined that the causes of jockey falls are related to a combination of jockey (sex, experience, previous meeting rides), horse (age, rating, race grade) and environmental (track distance, condition, field size) factors with both jockey and horse inexperience positively associated with jockey falls (Hitchens *et al.*, 2011; Hitchens *et al.*, 2010; O'Connor *et al.*, 2018; Tanner *et al.*, 2016).

The incidence of jockey falls in New Zealand between 2008 – 2013 was 2.2 per 1,000 rides for flat racing and 84.7 per 1,000 rides for jumps racing with 19% and 17% of jockey falls respectively resulting in injury (Bolwell *et al.*, 2014). The pattern of riding, training, track surfaces, racing conditions and regulation vary between jurisdictions, resulting in different risk factors and jockey fall rates worldwide. The temperate climate of New Zealand permits racing year-round on approximately 50 different 1,800 m turf tracks, with generally consistent dimensions and surfaces (Rogers *et al.*, 2014). A median of 5,893 horses and 191 licensed jockeys annually contribute to a median of 32,586 starts during a racing season (Bolwell *et al.*, 2016). Rating (flat, hurdles or steeples) is a dynamic measure of a horse's performance and is recalculated within two days of a horse's most recent race start (New Zealand Thoroughbred Racing, 2019a). Most races in New Zealand are handicap races (where higher weights are assigned to each horse based on their merits) including maiden races (albeit within a limited range of lower weights) and a small number of high stakes races (New Zealand Thoroughbred Racing, 2019a). High stakes races are held later in the day and in summer for flat racing. In contrast to the UK and US, both flat and jumps racing are held on the same day and track, thus enabling jockeys to ride in both types of race on the same day.

The high-risk nature of a jockey's occupation highlights the importance of investigating the causes of race-day jockey falls. Determining these can provide benchmarks for intervention strategies to mitigate the risk of jockey falls. No studies have specifically focused on risk factors to the jockey for flat and jumps racing jockey falls in New Zealand. The objectives of this study were to determine the incidence of and risk factors for race-day jockey falls occurring in New Zealand Thoroughbred flat and jumps racing.

2.4 Methods

Data were provided by New Zealand Thoroughbred Racing (NZTR), the governing body for Thoroughbred racing in New Zealand. Jockey, horse, and track condition data for every Thoroughbred race between 1 August 2005 and 17 April 2019 were provided. A jockey fall was defined as a rider being dislodged from a horse, or a horse falling (resulting in rider dislodgement), between the start of the race and the horse crossing the finishing line. This information was recorded as "Lost Rider" or "Fall" as the finishing position for the horse in the dataset. Jockeys could have more than one fall per race meeting, but no more than one fall per race.

For the purposes of this study, an apprentice was defined as any rider with a weight reduction of > 1 kg from the handicap weight assigned to the horse. Apprentices claim a weight reduction (allowance) of 0 - 4 kg on the handicap weight of horses they ride based on their experience as measured by previous wins. Ride number on a race-day for each jockey was determined iteratively based on race-day date, with the maximum number of rides on a race-day determined as the highest ride number for each date. Maximum number of race-day rides and ride number on race-day for jumps jockeys included both hurdle and steeplechase races for the calculation of incidence rate of race-day falls.

Incidence rates for jockey falls were calculated based on the number of falls and the number of rides during the time period and expressed as a rate per 1,000 rides. Normality of the data was assessed using an Anderson-Darling test and Pearson's chi-squared test was used to determine differences in jockey fall rates between different race types. The number of falls per jockey, stratified by race type, was summarized as median and interquartile range (IQR) for non-normally distributed data. Linear regression was used to calculate changes in jockey falls over the period.

Analyses were conducted separately for flat, hurdle and steeplechase racing. Univariable analysis using Poisson regression in a generalized linear mixed model was used to identify variables significantly associated with jockey falls at $p < 0.2$; these variables were then included in a multivariable model. The multivariable models were built using a backwards selection procedure whereby variables that improved the model, based on a chi squared likelihood ratio test ($p \leq 0.05$), were retained in the model. Predictor variables were race-level variables of interest; season, race distance, track condition and number of starters, horse-level variables; horse sex, age, rating (flat, hurdles or steeples) and carried weight (kg), jockey-level variables; jockey experience (apprentice or jockey), gender, age, ride number on a race-day and maximum number of rides on a race-day for the jockey. Including jockey or horse as a random effect did not improve model fit. Falling in one race was modelled as a risk factor for falling again the same day for jumps racing. All statistical analyses were conducted using RStudio (version 3.5.1, 2018; R Foundation for Statistical Computing, Vienna, Austria) with the level of significance set at $p < 0.05$.

2.5 Results

Summary race-day data for fourteen seasons (2005/6 - 2018/19) of flat, hurdle and steeplechase races are presented in Table 2.1. Flat racing accounted for 97% of races and most commonly had 10 races per race-day and jumps racing days had 2 races per race-day. The rate of jockey falls was higher in hurdle racing than flat racing ($p < 0.001$) and higher in steeplechase racing than both hurdle and flat racing ($p < 0.001$) (Table 2.1).

Table 2.1 Summary data, incidence rates (IR) and incidence rate ratios (IRR) for jockey falls occurring in flat, hurdle and steeplechase racing in New Zealand from 2005/6 – 2018/19 racing seasons (95% CI in brackets)

Race Type	**Starts**	**Jockeys**	**Jockey Falls**	**IR (per 1,000)**	**IRR (95% CI)**	**p**	**p (Wald)**
Flat	407,948	757	491	1.2 (1.1 – 1.3)	1.00	-	
Hurdle	8,395	169	447	53.2 (48.7 – 58.3)	44 (39 – 50)	<0.001	<0.001
Steeple	5,253	139	525	99.9 (92.2 – 108.4)	83 (73 – 94)	<0.001	
Total	421,596	787	1,460	3.5 (3.3 – 3.6)			

The incidence rates of jockey falls per season, stratified by race type are shown Figure 2.1. Jockey fall rates in flat racing decreased by 4% ($R^2 = 0.5$) over the study period. Jockey falls in hurdle racing reduced by 2% ($R^2 = 0.2$) and there was no change in steeplechase racing ($R^2 = 0.006$) over the study period.

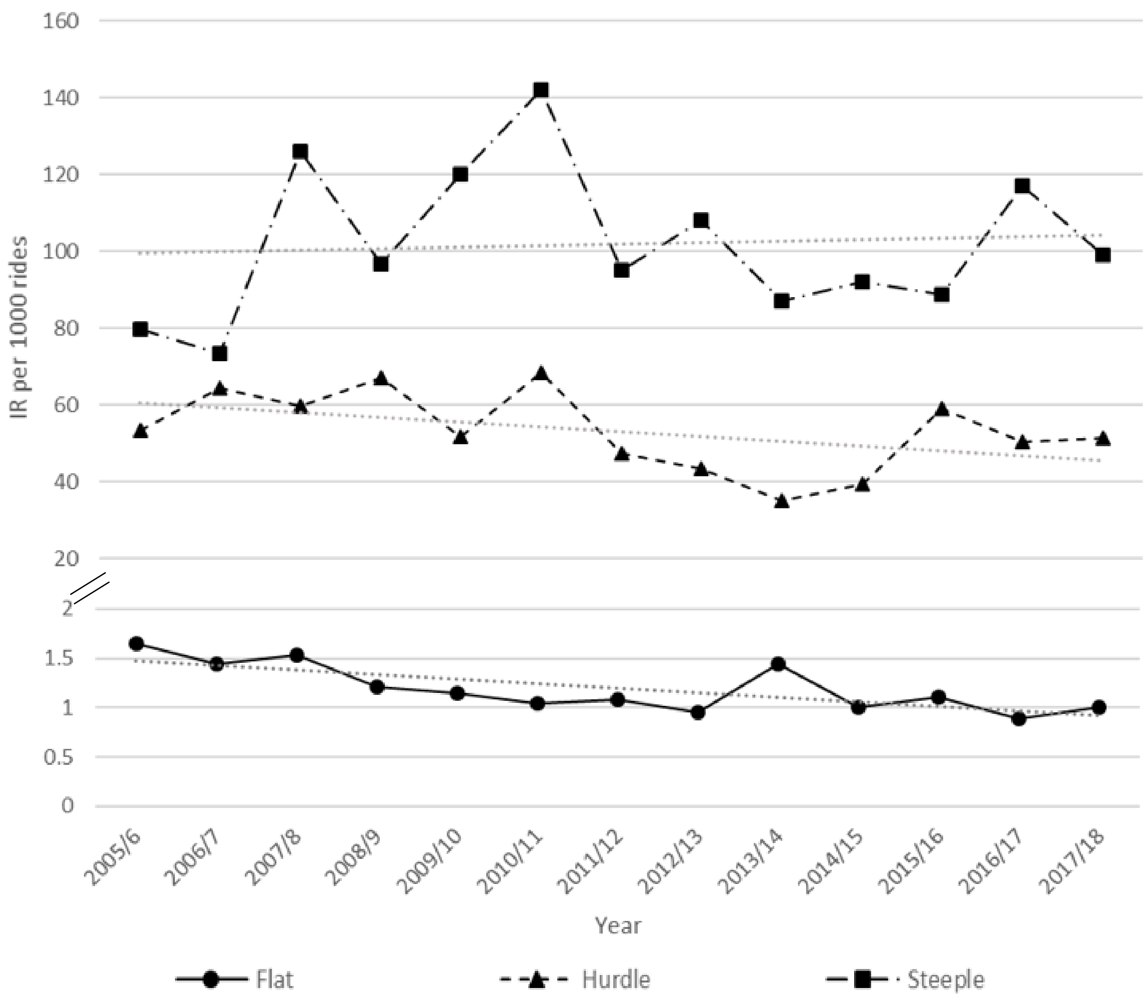

Figure 2.1 Jockey race day fall incidence rate (IR) occurring in flat, hurdle and steeplechase racing in New Zealand from the 2005/6 - 2017/18 racing seasons.

2.5.1 Flat racing

The median number of falls per jockey in flat racing was 2 (IQR 1 - 3) and 27% of all jockeys had a fall. No jockey had more than one fall on a race-day, and 43% of the jockeys that fell continued riding on the same race-day. There were 31,561 horses with starts in flat racing, from which 2% were involved in jockey falls and 3% of these were involved in 2 or more jockey falls.

Univariable analysis identified ten risk factors for jockey falls in flat racing: seasons of the year, track conditions, horse age, jockey experience, carried weight, flat rating, number of starters, jockey age, maximum number of race-day rides and the number of races previously completed by the jockey on a race-day (lowest IRR occurred at four race-day rides) (Appendix A).

Six variables predicted jockey falls in a multivariable analysis of flat racing (Table 2.2). Incidence rate ratio (IRR) increased linearly with the number of race-day rides by the jockey (R^2 = 0.9). There were higher jockey fall rates in summer in comparison to autumn. Middle rated (Rating 75) horses, older horses, a higher weight allowance, and a higher maximum number of rides on a race-day were associated with lower risks of jockey fall in flat racing.

Table 2.2 Multivariable Poisson regression of association between jockey falls in flat races and predictor variables; season of the year, horse age, carried weight (kg), flat rating (of horse), maximum number of race-day rides and the number of races previously ridden by the jockey on a race-day.

Variable	Category	Estimate	SE	IRR	95%CI	P	P (Wald)
Intercept		-5.11	0.18				
Season	Autumn	1.00	-	-	-	-	<0.001
	Winter	-0.17	0.15	0.84	(0.62-1.14)	0.26	
	Spring	0.22	0.13	1.25	(0.96-1.62)	0.10	
	Summer	0.52	0.12	1.68	(1.32-2.14)	<0.001	
Horse Age (years)	2-3	1.00	-	-	-	-	0.006
	4	-0.22	0.12	0.81	(0.64-1.02)	0.07	
	5	-0.30	0.14	0.74	(0.56-0.97)	0.03	
	6-13	-0.54	0.15	0.58	(0.43-0.79)	<0.001	
Carried Weight (kg)	< 54	1.00	-	-	-	-	0.007
	54 - 56	-0.09	0.13	0.92	(0.71-1.19)	0.52	
	56 - 58	-0.34	0.14	0.71	(0.55-0.93)	0.01	
	58+	-0.44	0.17	0.65	(0.46-0.90)	0.01	
Flat Rating	Maiden <55	1.00	-	-	-	-	0.002
	Rating 65	-0.26	0.12	0.77	(0.61-0.98)	0.03	
	Rating 75	-0.56	0.14	0.57	(0.44-0.75)	0.00	
	Rating 85	-0.13	0.17	0.88	(0.63-1.24)	0.47	
	Open >85	-0.34	0.21	0.71	(0.47-1.08)	0.11	
Max number of race-day rides	1	1.00	-	-	-	-	<0.001
	2	-0.74	0.18	0.48	(0.34-0.68)	<0.001	
	3	-1.38	0.20	0.25	(0.17-0.37)	<0.001	
	4	-2.01	0.22	0.13	(0.09-0.20)	<0.001	
	5	-2.14	0.22	0.12	(0.08-0.18)	<0.001	
	6	-2.40	0.23	0.09	(0.06-0.14)	<0.001	
	7	-2.62	0.25	0.07	(0.04-0.12)	<0.001	
	8	-3.15	0.30	0.04	(0.02-0.08)	<0.001	
	9+	-3.38	0.34	0.03	(0.02-0.07)	<0.001	
Ride number on race-day	1	1.00	-	-	-	-	<0.001
	2	0.46	0.15	1.58	(1.17-2.13)	0.003	
	3	0.84	0.18	2.31	(1.63-3.28)	<0.001	
	4	0.95	0.21	2.59	(1.71-3.91)	<0.001	
	5	1.23	0.23	3.43	(2.18-5.39)	<0.001	
	6	1.55	0.26	4.70	(2.83-7.83)	<0.001	
	7+	1.92	0.28	6.85	(3.96-11.85)	<0.001	

2.5.2 Hurdle racing

The median number of falls per jockey in hurdle racing was 3 (IQR 1 - 5) and 60% of jockeys had at least one fall. Three percent of jockeys had more than one fall on a race-day. Over half (57%) jockeys that fell continued riding on the same race-day. There were 1,716 horses racing over hurdles, of which 23% were involved in jockey falls and 12% of these were involved in 2 or more jockey falls.

Univariable analysis identified seven risk factors for jockey falls in hurdle races: race distance, track condition, horse sex, carried weight, hurdles rating, number of maximum race-day rides and number of races previously completed by the jockey on race-day (Appendix B).

Five variables predicted jockey falls in in a multivariable analysis of hurdle racing (Table 2.3). Shorter races, a heavy track, allocated weights between 64 - 66 kg, middle rated (rating 85) horses, and jockeys who had a higher maximum number of rides on a race-day were associated with lower risks of a jockey fall in hurdle racing.

Table 2.3 Multivariable Poisson regression of association between jockey falls in hurdle races and predictor variables; race distance (m), track condition (fast, good, dead, slow or heavy), weight carried during the race, hurdles rating of the horse and maximum number of race-day rides by the jockey.

Variable	Category	Estimate	SE	IRR	95%CI	P	P (Wald)
Intercept		-1.69	0.19				<0.001
Race Distance (m)	2400 - 2800	-0.66	0.15	0.52	(0.38-0.69)	<0.001	<0.001
	2800 - 3100	-0.33	0.13	0.72	(0.56-0.92)	0.009	
	3100 - 4400	1.00	-	-	-	-	
Track Condition	Fast	-0.85	1.01	0.43	(0.02-1.94)	0.4	0.01
	Good	-0.07	0.24	0.93	(0.57-1.46)	0.8	
	Dead	1.00	-	-	-	-	
	Slow	-0.02	0.14	0.98	(0.75-1.29)	0.9	
	Heavy	-0.36	0.13	0.70	(0.54-0.91)	0.007	
Carried Weight (kg)	< 64	1.00	-	-	-	-	0.04
	64 - 66	-0.30	0.12	0.74	(0.58-0.93)	0.01	
	66+	-0.13	0.12	0.87	(0.69-1.11)	0.3	
Hurdles Rating	Maiden	1.00	-	-	-	-	0.02
	Rating 65	-0.29	0.13	0.74	(0.58-0.95)	0.02	
	Rating 75	-0.33	0.14	0.72	(0.54-0.95)	0.02	
	Rating 85	-0.57	0.21	0.57	(0.37-0.84)	0.007	
	Open	-0.25	0.17	0.78	(0.56-1.07)	0.1	
Max number of race-day rides	1	1.00	-	-	-	-	<0.001
	2	-0.41	0.13	0.67	(0.52-0.86)	0.001	
	3	-0.60	0.14	0.55	(0.42-0.73)	<0.001	
	4+	-0.68	0.14	0.51	(0.39-0.67)	<0.001	

2.5.3 Steeplechase racing

The median number of falls per jockey in steeplechase racing was 3 (IQR 1 - 8) and 75% of jockeys had a fall. Few steeplechase jockeys (6% of those that fell) had more than one fall on a race-day, and 45% of jockeys that fell continued riding on the same race-day. There were

813 horses with steeplechase starts from which 42% horses were involved in jockey falls and 34% of these were involved in 2 or more jockey falls. Falling in one jumps (hurdle or steeplechase) race was a risk factor for falling again on race-day (IRR 1.5, 95% CI 1.3 - 1.7, $p < 0.001$).

Univariable analysis identified nine risk factors for steeplechase racing: season of the year, race distance, track condition, horse age, jockey experience, carried weight, steeples rating, jockey age and maximum number of race-day rides by the jockey (Appendix C).

Five variables predicted jockey falls in a multivariable analysis of steeplechase racing (Table 2.4). Winter racing, older jockeys (over 35 years), jockey experience, three race-day rides and higher rated horses were associated with lower risks of jockey fall.

Table 2.4 Multivariable Poisson regression of association between jockey falls in steeplechase races and predictor variables; season of the year, jockey experience (apprentice or jockey), steeples rating of the horse, jockey age and maximum number of race-day rides by the jockey.

Variable	Category	Estimate	SE	IRR	95%CI	P	P (Wald)
Intercept		-1.22	0.17				<0.001
Season	Autumn	1.00	-	-	-	-	0.10
	Winter	-0.25	0.11	0.78	(0.63-0.98)	0.03	
	Spring	-0.18	0.14	0.84	(0.63-1.11)	0.22	
Experience	Apprentice	1.00	-	-	-	-	0.08
	Jockey	-0.19	0.11	0.83	(0.67-1.02)	0.07	
Steeples Rating	Maiden	1.00	-	-	-	-	<0.001
	Rating 65	-0.54	0.12	0.58	(0.46-0.74)	<0.001	
	Rating 75	-0.50	0.13	0.61	(0.47-0.79)	<0.001	
	Rating 85	-0.66	0.16	0.52	(0.37-0.70)	<0.001	
	Open	-0.53	0.13	0.59	(0.45-0.77)	<0.001	
Jockey Age (years)	17 - 28	1.00	-	-	-	-	0.09
	29 - 33	-0.01	0.11	0.99	(0.80-1.23)	0.96	
	34 - 35	-0.10	0.13	0.90	(0.70-1.16)	0.43	
	35+	-0.35	0.15	0.70	(0.52-0.94)	0.02	
Max number of race-day rides	1	1.00	-	-	-	-	0.03
	2	-0.28	0.14	0.76	(0.57-1.01)	0.05	
	3	-0.44	0.15	0.64	(0.48-0.87)	0.004	
	4+	-0.33	0.15	0.72	(0.54-0.96)	0.02	

2.6 Discussion

The rates reported in the current study agree with previous jockey fall incidence rates of 0.9 per 1,000 rides and 84 per 1,000 rides for flat and jumps racing respectively, as reported by Bolwell *et al.* (2014). These findings are similar to those found previously in Australia, Ireland, United States, Britain and France (Balendra *et al.*, 2008; Forero Rueda *et al.*, 2010; Hitchens *et al.*, 2009; Hitchens *et al.*, 2013; O'Connor *et al.*, 2017). Over the fourteen seasons, incidence rates of jockey falls in flat and hurdle racing decreased; a small but encouraging trend. However, jockey fall rates for steeplechase racing varied greatly (70 – 140 per 1,000 rides) with no significant trend. There were more than twice the number of jockeys involved in flat racing compared to hurdle and steeplechase racing over the fourteen seasons; in total jumps racing accounted for only 3% of all races annually. This lack of opportunity may result in jockeys being less than optimally prepared for jumps racing in comparison to flat. Combined with the higher risk of jumps racing (Balendra *et al.*, 2008; Bolwell *et al.*, 2014; Forero Rueda *et al.*, 2010; Hitchens *et al.*, 2009; O'Connor *et al.*, 2017; Turner *et al.*, 2002), this could result in the more variable fall rate. This study has identified factors which may be used to improve health and safety standards which may further reduce risk of jockey falls for all race types (but particularly steeplechase racing).

Jockeys were less likely to fall in any race if they had a greater maximum number of race-day rides. Maximum number of race-day rides could be used as a measure of jockey experience, as professional jockeys with higher success rates and a better reputation may have more rides scheduled on a race-day than newer, less skilled or inexperienced jockeys. In addition, jockeys over 35 years of age in steeplechase races (probable to have had longer careers and thus more experience) were less likely to fall than those under 28 years of age. This was similar to findings in Australia, Ireland and New Zealand where less experienced jockeys or apprentices (classified by number of career rides) had higher fall rates than professional jockeys (Hitchens *et al.*, 2012; O'Connor *et al.*, 2018; Tanner *et al.*, 2016). In the United Kingdom, horses have a lower risk of fatal limb fracture when ridden by more experienced jockeys (Parkin *et al.*, 2004) and amateur jockeys have a higher rate of falls and fracture incidence than professional jockeys in Ireland point to point (jumps) racing (O'Connor *et al.*, 2018).

Apprentice jockeys were only associated with a greater risk of jockey falls in steeplechase racing. Apprentice and amateur riders were associated with jockey falls in jumps racing in Ireland and both flat and jumps racing in Australia (Hitchens *et al.*, 2011; Hitchens *et al.*, 2012; O'Connor *et al.*, 2018). Jockey inexperience or lack of physical conditioning may be more apparent in steeplechase races than in shorter flat races due to their length and inclusion of jumps (Hitchens *et al.*, 2011). In addition, there could be a greater difference in skill between professional and junior jockeys in jumps racing, due to lower numbers of jockeys with fewer races compared to flat racing. Thus, inexperience may be more apparent as a risk factor in jumps racing than in flat racing.

Ride number on a race-day was linearly associated with an increasing risk of jockey fall for flat racing, indicating that the physical fitness (and fatigue) of jockeys riding in multiple races is an important factor influencing falls. This variable accounts for the accumulation of rides on a race day, as opposed to the maximum number of race day rides which was used a measure of jockey experience, and as such is a better measure of jockey daily physiological workload. Both factors reflect the greater time spent at risk by those jockeys. More competitive (higher stakes) races are later in the day, where jockeys may be more likely to take higher risks to win. Jockey fall rates in Australia increased with number of rides in short steeplechase races and with longer races (Hitchens *et al.*, 2011) similar to the lower incidence of jockey falls at shorter hurdle racing distances in this study, indicating that jockey fatigue may affect fall rates. The low number of hurdle and steeplechase races held on a race-day in New Zealand may be the reason this effect was not apparent in jumps racing in the current study.

Information on jockey fatigue during races, race-day and training workloads, physical fitness (both aerobic and anaerobic) and muscular strength as well as physiological attributes and physical conditioning programmes are important avenues for further investigation.

Falling in one race was a risk factor for falling again that race-day for jockeys in both hurdle and steeplechase races. Jockeys were seen by a medical person on course for only 25% of jockey falls in jumps racing in New Zealand between the years 2008 - 2013 with 71% 'not stated' if they were seen by a medical professional (physician) on course (Bolwell *et al.*, 2014). Undiagnosed injuries (or those masked by the jockey) sustained in a fall could impact their subsequent riding ability, in addition to contributing to the possible effects of fatigue riding in multiple races; both conditions increasing the chances of errors resulting in jockey falls. Appropriate medical evaluation of jockeys after any fall may be an important regulation to reduce risk of further falls.

Jockeys were less likely to fall in any race if they rode higher rated horses, similar to the association previously reported between jockey falls and rating in New Zealand flat racing (Tanner *et al.*, 2016). Higher rated horses have had more success racing than their counterparts, who may be new to racing and therefore be more likely to behave unpredictably, increasing risk of jockey falls. Less accomplished horses (measured by lower race grade, fewer previous starts and lower stakes races) and younger horses were also associated with a higher jockey fall risk in Australia (Hitchens *et al.*, 2010; Hitchens *et al.*, 2012). Horse age, a factor in flat racing, may not have been significant in jumps racing due to the older ages of horses in these races (Bolwell *et al.*, 2017).

Jockeys were less likely to fall from horses carrying higher weights in both flat and hurdle racing. Horses that have won more races are assigned higher weights, another indicator of more accomplished horses. In addition, a higher weight allowance could mean less wasting (methods to reduce weight) for the jockey. Rapid weight loss methods, commonly used by jockeys have been shown to impair physical performance in jockeys (Dolan *et al.*, 2013; Wilson *et al.*, 2014). However, jockey specific weights were not recorded in these data, so this effect could not be investigated. Biometric assessments of jockeys could provide valuable data for further research into the effects of making weight on jockey performance.

There was a higher incidence of jockey falls during flat racing in summer, similar to that found by Tanner *et al.* (2016). There is no seasonality of races in New Zealand (Bolwell *et al.*, 2016), so this was unlikely to be an effect from differences in race volume. However, higher stakes races take place in summer, and warmer weather is likely to make the tracks harder, both factors contributing to faster, more competitive races. Although not significant in this study, drier tracks were associated with jockey falls in flat races in Australia (Hitchens *et al.*, 2010) and horse falls in the Grand National in Britain (Proudman *et al.*, 2004), but not in Australian jumps races (Hitchens *et al.*, 2011). Warmer summer weather may contribute to jockey fatigue, especially in those who may be dehydrated to make weight (Leydon *et al.*, 2002; O'Reilly *et al.*, 2017). Furthermore, when dehydration is combined with exercise-induced fatigue, greater decrements may be seen in physical performance (Dolan *et al.*, 2013; Wilson *et al.*, 2014) and cognitive function (Mündel *et al.*, 2015), and as a result, racing errors. These factors combined could contribute to the higher incidence of jockey falls in summer but requires further investigation of jockey physiological attributes to determine the demands placed on the jockey.

Jockey falls in this study were investigated only for the duration of the race. However, this accounts for only a proportion of the time the jockey is mounted on the horse on race day, and 42% and 99% of flat and jumps racing days falls respectively (Bolwell *et al.*, 2014). Pre-race activities accounted for 47% and 1% respectively of flat and jumps racing jockey falls whilst post-race activity accounted for 11% of flat racing jockey falls (Bolwell *et al.*, 2014). Falls that occur before the race may be associated with inexperienced horses and/or riders, whereas falls after the race may be associated with jockey fatigue, warranting further investigation.

A major strength of the study is that it provides current and long-term trends of jockey fall rates. However, the possibility of random error in a large dataset is inherent. Maximum number of race-day rides was determined retrospectively from the recorded data, and included some loss to follow up from the 17% of flat and 14% of jumps jockeys stood down after falls (including pre- and post- race falls) (Bolwell *et al.*, 2014). In addition, overseas jockeys may fly in specifically to ride in a premiership race and have a low number of rides on a race-day. Both occurrences affect the association between maximum number of race-day rides and experience. However, these incidences are few and have minimal effect in the large data set.

2.7 Conclusions

The incidence of race-day jockey falls in New Zealand were higher in jumps racing compared to flat racing, similar to published data. Experienced athletes (both jockey and horse), measured by maximum number of race-day rides, age, horse rating and carried weight, had lower risks of jockey falls. The linearity of IRR with number of race-day rides and the lower IRR associated with shorter distances in jumps racing indicate that the physical fitness and fatigue of professional jockeys may play a role in the risk of race-day falls. Future research should assess jockey workloads and the demands of racing to facilitate sport-specific conditioning programmes for jockeys and determine their effectiveness in reducing fall rates.

2.8 Practical implications

- There was a small decrease in jockey falls for flat and hurdle racing and no change for steeplechase racing between 2005/6 – 2018/19 racing seasons, indicating that targeted strategies to reduce fall risk in jockeys could improve their health and safety.
- Athlete (jockey and horse) experience are associated with lower risk of a jockey fall
- Jockey fatigue may be an important contributor to jockey falls and injury, highlighting the need to investigate sport-specific conditioning programmes for jockeys to determine their potential to reduce risk.

2.9 References

Balendra, G., Turner, M., & McCrory, P. (2008). Career-ending injuries to professional jockeys in British horse racing (1991-2005). *British Journal of Sports Medicine,* 42(1): 22-24. doi:10.1136/bjsm.2007.038950

Balendra, G., Turner, M., McCrory, P., & Halley, W. (2007). Injuries in amateur horse racing (point to point racing) in Great Britain and Ireland during 1993-2006. *British Journal of Sports Medicine,* 41(3): 162-166. doi:10.1136/bjsm.2006.033894

Bolwell, C. F., Rogers, C. W., & Gee, E. K. (2014). Descriptive epidemiology of race-day jockey falls and injuries in New Zealand. *Comparative Exercise Physiology,* 10(1): 49-55. doi:10.3920/cep13036

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science,* 56(1): 77- 81. doi:10.1071/an13442

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2017). Commercial equine production in New Zealand. 3. The racing and sport industries. *Animal Production Science*: A-K. doi:10.1071/an16753

Brooks, J. H., Fuller, C. W., Kemp, S. P., & Reddin, D. B. (2005). Epidemiology of injuries in English professional rugby union: part 1 match injuries. *British Journal of Sports Medicine,* 39(10): 757-766. doi:10.1136/bjsm.2005.018135

Curry, B. A., Hitchens, P. L., Otahal, P., Si, L., & Palmer, A. J. (2016). Australian insurance costs of jockeys injured in a race-day fall. *Occupational Medicine,* 66(3): 222-229. doi:10.1093/occmed/kqv150

Dolan, E., Cullen, S. J., McGoldrick, A., & Warrington, G. D. (2013). The impact of making weight on physiological and cognitive processes in elite jockeys. *International Journal of Sport Nutrition and Exercise Metabolism,* 23: 399 -408.

Forero Rueda, M. A., Halley, W. L., & Gilchrist, M. D. (2010). Fall and injury incidence rates of jockeys while racing in Ireland, France and Britain. *Injury,* 41(5): 533-539. doi:10.1016/j.injury.2009.05.009

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011). Predictors of race-day jockey falls in jumps racing in Australia. *Accident Analysis and Prevention,* 43(3): 840-847. doi:10.1016/j.aap.2010.11.003

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L., & Fell, J. (2010). Predictors of race-day jockey falls in flat racing in Australia. *Occupational and Environmental Medicine,* 67(10): 693-698. doi:10.1136/oem.2009.050567

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2009). The incidence of race-day jockey falls in Australia, 2002–2006. *The Medical Journal of Australia,* 190(2): 83-86. doi:10.5694/j.1326-5377.2009.tb02284.x

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2012). The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention,* 18(6): 385-391. doi:10.1136/injuryprev-2011-040255

Hitchens, P. L., Hill, A. E., & Stover, S. M. (2013). Jockey falls, injuries, and fatalities associated with Thoroughbred and quarter horse racing in California, 2007-2011. *Orthopaedic Journal of Sports Medicine,* 1(1): 1-7. doi:10.1177/2325967113492625

Leydon, M. A., & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12: 220-237.

McCrory, P., Turner, M., LeMasson, B., Bodere, C., & Allemandou, A. (2006). An analysis of injuries resulting from professional horse racing in France during 1991-2001: a comparison with injuries resulting from professional horse racing in Great Britain during 1992-2001. *British Journal of Sports Medicine,* 40(7): 614-618. doi:10.1136/bjsm.2006.028449

Mündel, T., Hill, S., & Legg, S. (2015). Hypohydration per se affects mood states and executive cognitive processing: results from a face-valid model for studying some consequences of 'voluntary dehydration'. *Extreme Physiology & Medicine,* 4(S1). doi:10.1186/2046-7648-4-s1-a97

New Zealand Thoroughbred Racing. (2019a). *Handicapping guide*. Wellington, New Zealand: Available from: https://loveracing.nz/OnHorseFiles/LoveRacing/Articles/2018/2019%20Handicapping%20Policy%20(Effective%20from%201%20August%202019).pdf. Accessed: Jan 2020

New Zealand Thoroughbred Racing. (2019b). *NZTR Racing Policy*. Available from: https://loveracing.nz/OnHorseFiles/RACING%20POLICY%202019.pdf. Accessed: Jan 2020.

O'Connor, S., Warrington, G., McGoldrick, A., & Cullen, S. (2018). A 9-year epidemiologic study (2007-2015) on race-day jockey fall and injury incidence in amateur Irish horse racing. *Journal of Athletic Training,* 53(10): 950-955.

O'Connor, S., Warrington, G., McGoldrick, A., & Cullen, S. J. (2017). Epidemiology of injury due to race-day jockey falls in professional flat and jump horse racing in Ireland, 2011-2015. *Journal of Athletic Training,* 52(12): 1140-1146. doi:10.4085/1062-6050-52.12.17

O'Reilly, J., Cheng, H. L., & Poon, E. T.-C. (2017). New insights in professional horse racing; "in-race" heart rate data, elevated fracture risk, hydration, nutritional and lifestyle analysis of elite professional jockeys. *Journal of Sports Sciences,* 35(5): 441-448. doi:10.1080/02640414.2016.1171890

Parkin, T. D. H., Clegg, P. D., French, N. P., Proudman, C. J., Riggs, C. M., Singer, E. R., . . . Morgan, K. L. (2004). Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal,* 36 (6): 521-526.

Proudman, C., Pinchbeck, G., Clegg, P., & French, N. (2004). Risk of horses falling in the Grand National. *Nature,* 428(6981): 385-386. doi:10.1038/nature02481

Rogers, C. W., Bolwell, C. F., Gee, E. K., Peterson, M. L., & McIlwraith, C. W. (2014). Profile and surface conditions of New Zealand Thoroughbred racetracks. *Journal of Equine Veterinary Science,* 34(9): 1105-1109. doi:10.1016/j.jevs.2014.06.017

Tanner, J., Rogers, C., Bolwell, C., Cogger, N., Gee, E., & McLlwraith, W. (2016). Analysis of failure to finish a race in a cohort of Thoroughbred racehorses in New Zealand. *Animals,* 6(6). doi:10.3390/ani6060036

Turner, M., McCrory, P., & Halley, W. (2002). Injuries in professional horse racing in Great Britain and the Republic of Ireland during 1992-2000. *British Journal of Sports Medicine,* 36: 403-409.

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

Wilson, G., Hawken, M. B., Poole, I., Sparks, A., Bennett, S., Drust, B., . . . Close, G. L. (2014). Rapid weight-loss impairs simulated riding performance and strength in jockeys: implications for making-weight. *Journal of Sports Sciences,* 32(4): 383-391. doi:10.1080/02640414.2013.825732

3 Chapter Three - The external workload of Thoroughbred horse racing jockeys

Published in part in the following publication.

Legg, K. A., Cochrane, D., Gee, E., & Rogers, C. (2020). The external workload of Thoroughbred horse racing jockeys. *Sustainability*, 12(18). doi:10.3390/su12187572

3.1 Foreword to Chapter Three

The previous chapter demonstrated that experienced jockeys (and horses) had a lower incidence of falls than inexperienced jockeys. Jockeys with fewer race rides were more likely to have a fall indicating that there may be some need for “race specific fitness”. This highlighted the role that sport specific training may have on reducing injury risk, particularly in inexperienced jockeys. However, the amount of competitive riding undertaken by an individual jockey during a racing season and possible relationships to riding performance, experience or injury risk was unknown. Therefore, the next step in this research was to quantify the competitive workload (based on number of race day rides) for jockeys and apprentices in New Zealand and relate it to measures of performance and fall risk (safety). The following chapter examined the external workload of Thoroughbred horse racing jockeys.

3.2 Abstract

The objectives of this study were to quantify the external workload of Thoroughbred racing jockeys in relation to their experience and racing performance. The number of rides of 786 jockeys and apprentices who rode in 407,948 flat and 13,648 jumps racing starts over 14 seasons were examined. Jockey work (ride numbers, seasons riding) and performance characteristics (race falls or wins) between cohorts with low (1 - 10), middle (10 - 200) and high (> 200) numbers of rides per season were compared. Flat racing apprentices had more rides per season (25, IQR 7 - 97 vs 14, IQR 3 - 222, $p < 0.001$) but fewer rides per race-day (2, IQR 1 - 4 vs 4, IQR 2 - 6, $p < 0.001$) than flat racing jockeys. Flat racing jockeys in the high workload cohort (23%) were responsible for 83% of the race-day rides, riding in a median of 375 (IQR 283 - 520) races per season. These jockeys had half the fall rate (IR 1.0, 95% CI 0.9 - 1.1) and 1.4 times the success rates per 1,000 rides (IR 98, 95% CI 97 - 99) than jockeys in the low and middle cohorts ($p < 0.05$). Most jockeys had light workloads, greater risk of injury and lower winning rates than the smaller cohort of jockeys with heavier workloads. This disparity in opportunity and success between cohorts indicates inefficiencies within the industry in recruitment and retention of jockeys. These data provide a foundation to further studies investigating jockey competition specific fitness and its effect on both riding success and reducing injury risk.

3.3 Introduction

Thoroughbred racing is a major international sport that is of significant economic importance in 47 countries worldwide. In New Zealand it employs ~35,000 people, contributes ~1% towards gross domestic product (~NZ$1.4 billion) and attracts in excess of 350,000 spectators per year (IER, 2018). Thoroughbred racing is divided into flat and jumps racing, each operating with minimum riding weights, facilitated by a handicapping system to enable equal competition where better performing horses are allocated higher weights to equalize the chances of all competitors (New Zealand Thoroughbred Racing, 2019). Flat races are shorter than jumps races, occur year-round and comprise 96% of the total number of races in New Zealand, whereas jumps races occur only during the winter season and include up to 25 obstacles (Bolwell *et al.*, 2016). In New Zealand, there is a median of 2,934 (IQR 2,734 - 2,949) flat races per year with approximately 10 races per race-day. There are 122 (IQR 114 - 132) jumps races per year with approximately 2 races per race-day (Legg *et al.*, 2020).

At an industry level, much of the appeal of the Thoroughbred industry is based on tradition and the maintenance of traditional practices. Attention on the sustainability of the industry has primarily focused on the impact of these traditional practices on the horse, rather than a broader context of all industry participants (Bergmann, 2019; Legg *et al.*, 2019; Ruse *et al.*, 2015). Indeed, there appears to have been limited focus on how the workplace practises and physiological challenges of jockeys (high perceived workload and maintenance of low body weights) are sustainable within the industry, both from a health and safety and economic perspective. Jockeys have the responsibility of controlling both their individual riding performance as well as the performance of the horse, racing at speeds exceeding 60 $km \cdot h^{-1}$ on race-day (Pfau *et al.*, 2009; Speed, 2001; Warrington *et al.*, 2009). Added to this is the risk of falling from the horse, with incidence rates (per 1,000 starts) of 1.2 for flat and 53 – 100 for jumps racing (Legg *et al.*, 2020). Jockeys must comply with the weight allocation of each horse they ride, with minimum riding weights of 52 kg and 63 kg in operation for flat and jumps jockeys respectively. Apprentice jockeys are young professional jockeys who serve a four-year apprenticeship and are given a weight allowance of 1 – 4 kgs (based on their previous wins) under the weight assigned to the horse, to compensate for their inexperience in race riding (New Zealand Thoroughbred Racing, 2019). In the 2018/19 racing season, there were 146 jockeys who won at least one race and 47 registered apprentices.

Uncommon to athletes in other sports, jockeys have the unique demand placed on them to remain in peak physical condition and maintain a low weight, on a daily basis, with no off-season (Cullen *et al.*, 2015). Prescribing an optimal physical training load for an athlete depends on selecting an appropriate workload measure and quantifying the current workload status of the athlete (Bourdon *et al.*, 2017; Windt *et al.*, 2017). Race riding provides significant stress on the athlete (internal workload) with mean heart rates (HR) during a race of 90 – 98% their maximal HR (achieved at exhaustion), and respiration rates of 50 ± 7 breaths per minute for flat racing jockeys (Cullen *et al.*, 2015; O'Reilly *et al.*, 2017). Mean heart rates are over 80% maximal for national hunt (jumps) racing jockeys with no significant period of recovery between races (Trowbridge *et al.*, 1995). This suggests that during a race-day, jockeys experience intermittent periods of intense cardiovascular load amongst sustained periods of elevated heart rate.

The external workload of an athlete quantifies the amount of work they perform (Bourdon *et al.*, 2017; Windt *et al.*, 2017). The amount of external work performed by jockeys varies with the number of races ridden per race-day and race-days per season. Jockeys in the United States (USA) reported an average of 4.6 ± 1.7 rides per day and approximately 650 rides per year (Press *et al.*, 1995). Similarly, flat racing jockeys in Britain are qualitatively reported to compete in up to 5 - 7 races per day, up to 7 days a week with no defined off-season (Dolan *et al.*, 2011; Kiely *et al.*, 2020; Warrington *et al.*, 2009). Jockeys in New Zealand and Australia have been reported to have varying numbers of rides per week, riding 1 - 8 rides in 2 - 4 race meetings per week or 1 - 30 rides per week, and working (in horse related activities) 6 days a week (Leydon *et al.*, 2002; Speed, 2001). A study of retired jockeys in Victoria, Australia highlighted the large disparity between the number of rides of the top 25 jockeys who had on average four times the earnings of the majority (n = 110) of registered jockeys and were responsible for 70% of the total number of race-day rides (Speed, 2001).

The physiological workload of a jockey during a single race has been previously investigated, but the external workload of jockeys over a racing season has not been quantitatively measured and is important in both the prevention of jockey injury (due to falls or gradual onset due to repetitive loading) and when designing physical training programmes. At an industry level, it is important to understand the workflow and engagement of the participants in order to manage recruitment of apprentice jockeys and efficient utilisation of human resources. Based on the literature published and anecdotal observations, there may be a disequilibrium in the opportunities for participation in race day rides, and thus career success. Therefore, the aims of this study were to determine the workload (based on number of race-day rides) for jockeys and apprentices in New Zealand and to compare the characteristics and performance of jockeys with low, middle and high external workloads.

3.4 Materials and methods

Data from all Thoroughbred race starts between 1 August 2005 and 17 April 2019 were supplied by New Zealand Thoroughbred Racing (NZTR), the governing body for Thoroughbred racing in New Zealand. A racing season began on 1 August and ended on 31 July. Data were provided at the ride level and the following variables were extracted and used for further analysis: date of race; horse carried and assigned weight; jockey name, gender and age; race outcome (in the form of jockey falls or wins). Hurdle and steeplechase races were combined into one category of jumps races to allow comparison between flat and jumps races. For clarity, external workload in this study refers to the number of competitive race-day rides ridden by a jockey.

Derived variables were jockey and apprentice status. Carried weight refers to the weight carried by the horse during the race. For the purposes of this study, an apprentice was defined as a rider whose horses carried weight during a race was ≤ 1 kg from the handicap weight assigned to the horse (i.e., indicating the jockey had a weight allowance of ≥ 1 kg). Jockeys were categorised into three evenly populated cohorts of 'high', 'middle' and 'low' numbers of rides per season. For flat and jumps racing respectively, 200 or 25 rides per season were assigned to the high cohort, jockeys who rode 10 - 200 or 5 - 25 rides per season were assigned to the middle cohort and those who rode 1 - 10 or 1 - 5 rides per season were assigned to the low cohort. After characterising the cohorts for flat and jumps racing jockeys, all subsequent analyses were conducted for flat racing jockeys and apprentices only, due to the smaller number of rides by jumps racing participants.

The integrity of the data was checked using histograms and scatter plots, where outliers or points of interest were compared with the official NZTR database. Descriptive statistics were used to describe the data at population and seasonal (yearly) levels in terms of numbers of rides and seasons riding, stratified by flat and jumps races and by jockey and apprentice status. Mean and standard deviation (SD) were used to describe normally distributed population level data. Median and IQR were used to describe continuous data that were non-normally distributed and counts and percentages were used to describe categorical data. Frequencies per year of race start appearances were used to describe the jockey characteristics (gender and experience) in workload cohorts. Linear regression was used to calculate changes in median number of rides over the study period. Incidence rates were calculated based on the number of falls or wins and number of rides during the time period and expressed as a rate per 1000 rides. Normality was assessed using an Anderson–Darling test and Kruskal–Wallis tests for significance were used to compare differences between groups. Post hoc tests for significance between groups were assessed with the χ^2-test for frequency data and Mann–Whitney U tests for continuous data.

Analyses were conducted in RStudio (version 3.5.1, 2018; R Foundation for Statistical Computing, Vienna, Austria) with the level of significance set at $p < 0.05$.

3.5 Results

During the period 1 August 2005–17 April 2019, there were 37,596 flat races over 4459 race days and 1528 jumps (897 hurdle and 631 steeple) races over 536 race days. There was a total of 421,596 ride opportunities, of which 407,948 were flat racing starters and 13,648 jumps racing starters. There was a mean (± SD) of 21 ± 1 flat racing days per month, year-round. Jumps races had a defined season from March to July (winter) with an average of 7 ± 1 jumps racing days for each of these months. The average number of ride opportunities per season was 30,942 ± 2,226 and this decreased after the 2008/9 season in a linear relationship at a rate of 843 (3%) opportunities per season ($R^2 = 0.96$).

Data were collected for 786 jockeys and apprentices, the majority of which (n = 757, 96%) rode in flat races. Only 177 (23%) rode in a jumps race. During each racing season, there were an average of 190 ± 7 jockeys and 89 ± 7 apprentices that rode in at least one race. The median age of jockeys riding a race was 30 years (IQR 24 - 38, n = 330,988) and for apprentices was

22 years (IQR 19 - 25, n = 81,687). Male jockeys accounted for 69% of race rides and 61% of the total number of registered jockeys or apprentices over the study period.

Rides for both jockeys and apprentices had a skewed distribution, with a small number of jockeys who had large numbers of rides, and a large number of jockeys who had low numbers of rides (Table 3.1). Flat racing jockeys had more race days per season and rides per race day than jumps racing jockeys, and the majority of jockeys and apprentices rode for only two seasons. Flat racing jockeys had a greater variation in workload than flat racing apprentices. Jumps racing jockeys had a higher workload than jumps racing apprentices.

Table 3.1 Median and interquartile range (IQR) numbers of seasons riding, rides per race day, race days and rides per season for jockeys and apprentices stratified by race type from 1 August 2005 – 17 April 2019.

Variable		**Flat races**	**Jumps races**	
		Median (IQR)	**Median (IQR)**	**p***
Seasons race riding	Jockeys	2 (1–5)	2 (1–5)	0.7
	Apprentices	2 (1–3)	2 (1–3)	0.2
	p value	<0.001	<0.001	
Race days per season	Jockeys	10 (2–62)	6 (2–15)	<0.001
	Apprentices	15 (5–40)	5 (2–11)	<0.001
	p value	<0.001	0.04	
Rides per race day	Jockeys	4 (2–6)	2 (1–3)	<0.001
	Apprentices	2 (1–4)	1 (1–2)	<0.001
	p value	<0.001	<0.001	
Rides per season	Jockeys	14 (3–222)	9 (3–32)	0.7
	Apprentices	25 (7–97)	7 (2–16)	0.02
	p value	<0.001	0.09	

*p values calculated using Kruskal-Wallis test for non-normally distributed data.

The median number of rides per season for flat racing jockeys decreased by 8% per season ($R^2 = 0.7$) whilst that for flat racing apprentices increased by 3% ($R^2 = 0.4$, $p < 0.001$) over the study period, as shown in Figure 3.1. The median number of rides per season for apprentices in their last season (before becoming jockeys) was 216 (IQR 29–415), whereas the median number of rides in their first season riding as a licensed jockey was 74 (IQR 12 - 170, p = 0.2).

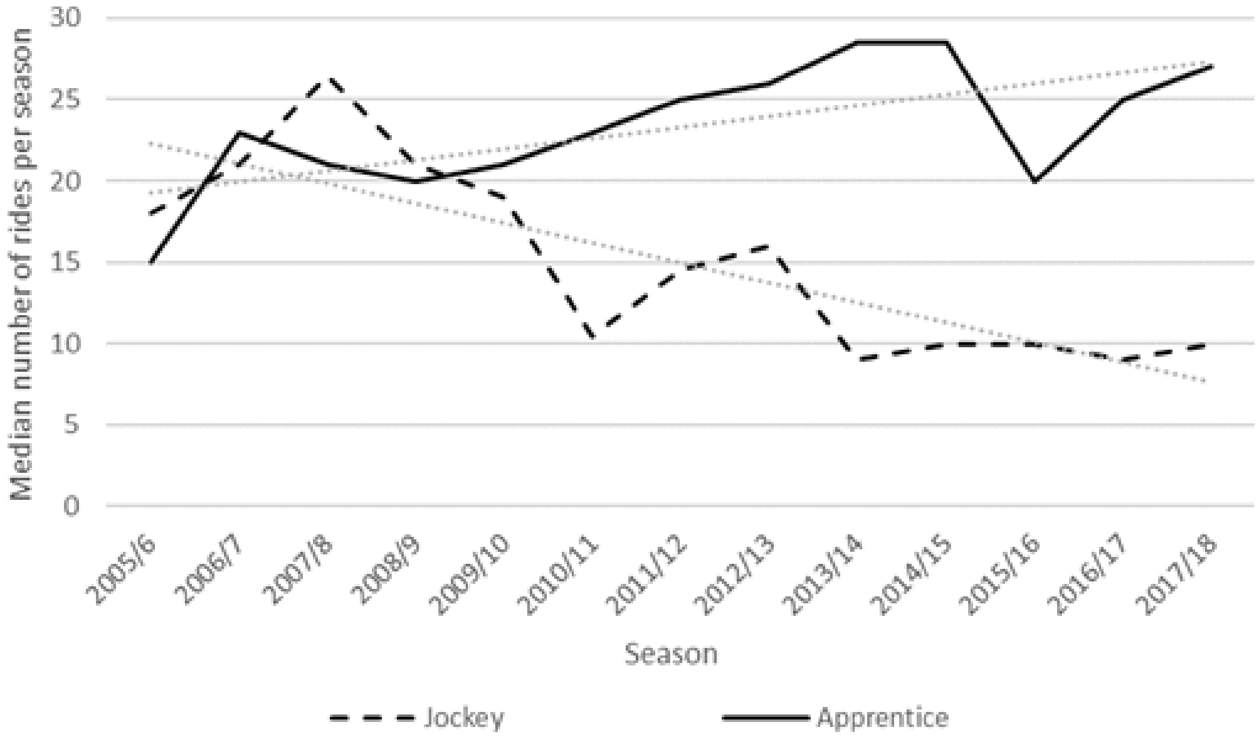

Figure 3.1 Median number of rides for flat racing jockeys and apprentices from 1 August 2005 – 31 July 2018.

3.1. Low, Middle and High Workload Cohort

The maximum number of rides in one season by one flat racing jockey was 1,173. Jockeys in the high workload cohort were more likely to be male and fully licensed jockeys than jockeys in the low or middle workload cohorts (Table 3.2). High workload cohort flat racing jockeys were able to consistently meet the low weights assigned to their horses. High workload cohort jockeys rode for more seasons and had half as many falls and more (1.4 times for flat and 1.3 - 2.7 times for jumps) wins per season than jockeys in the middle and low workload cohorts.

Table 3.2 Characteristics of jockeys with low (1 - 10 or 1 - 5), middle (10 - 200 or 5 - 25) and high (> 200 or > 25) number of rides per season stratified by flat and jumps racing, respectively, from 1 August 2005 – 17 April 2019.

	Flat				Jumps			
	Low	**Middle**	**High**	**p***	**Low**	**Middle**	**High**	**p***
Frequency of observations (%)								
Female	415 (41%)^{a}	371 (34%)^{b}	239 (30%)^{c}	<0.001	44 (22%)^{ac}	25 (13%)^{bc}	36 (17%)^{bc}	0.005
Male	595 (59%)	709 (66%)	561 (70%)		256 (78%)	169 (87%)	172 (83%)	
Apprentice	366 (24%)^{a}	605 (48%)^{b}	137 (17%)^{c}	<0.001	127 (38%)^{a}	123 (45%)^{ab}	41 (22%)^{c}	<0.001
Jockey	1,153 (76%)	660 (52%)	649 (83%)		205 (62%)	148 (55%)	145 (78%)	
Median (IQR)								
Rides per season	3 (1–6)^{a}	38 (20–98)^{b}	375 (283–520)^{c}	<0.001	2 (1–3)^{a}	13 (9–18)^{b}	48 (34–64)^{c}	<0.001
Race days per season	2 (1–4)^{a}	21 (12–39)^{b}	94 (72–114)^{c}	<0.001	2 (1–3)^{a}	7 (5–10)^{b}	21 (16–26)^{c}	<0.001
Rides per race day	1 (1–1)^{a}	2 (1–2)^{b}	4 (3–5)^{c}	<0.001	1 (1–2)^{a}	2 (1–2)^{b}	2 (2–3)^{c}	<0.001
Number of seasons in workload cohort	1 (1–2)^{a}	2 (1–3)^{b}	3 (1–6)^{c}	<0.001	1 (1–2)^{a}	1 (1–2)^{a}	3 (1–5)^{b}	<0.001
Number of seasons riding	1 (1–2)^{a}	3 (2–5)^{b}	6 (4–10)^{c}	<0.001	1 (1–1)^{a}	2 (2–4)^{b}	6 (4–8)^{c}	<0.001
Jockey age (yrs) at first appearance	24 (21–31)^{a}	22 (20–27)^{b}	23 (19–31)^{c}	<0.001	23 (20–27)^{a}	23 (21–27)^{a}	23 (20–26)^{a}	0.5
Horse carried weight (kg)	65 (56–68)^{a}	56 (54–58)^{b}	56 (55.5–56.5)^{c}	<0.001	65 (63–66)^{a}	65 (63–65)^{a}	65 (63–66)^{a}	0.3
Incidence Rate (95%Confidence Interval)								
Falls per 1000 rides	2.4 (1.1–4.5)^{a}	2.1 (1.8–2.5)^{a}	1.0 (0.9–1.1)^{b}	0.01	131 (105–164)^{a}	85 (75–96)^{b}	63 (59–68)^{c}	<0.001
Wins per 1000 rides	67 (59–75)^{a}	70 (68–72)^{a}	98 (97–99)^{b}	<0.001	44 (29–66)^{a}	95 (85–107)^{b}	120 (114–126)^{c}	<0.001

*p value calculated from Kruskal–Wallis test; values with different superscripts are significantly different within rows, p <0.05.

The high workload cohort of flat racing jockeys comprised 23% of the total number of jockeys riding in flat races but accounted for the majority (83%) of race-day rides (Figure 3.2). Flat racing jockeys who were classified as riding in the high workload cohort at least once during the study period spent a median of three seasons (IQR 1 - 6) riding in the high workload cohort but spent a median of two seasons (IQR 1 - 3) riding in the middle workload cohort and a median of 0 seasons (IQR 0 - 1) riding in the low workload cohort during their riding career.

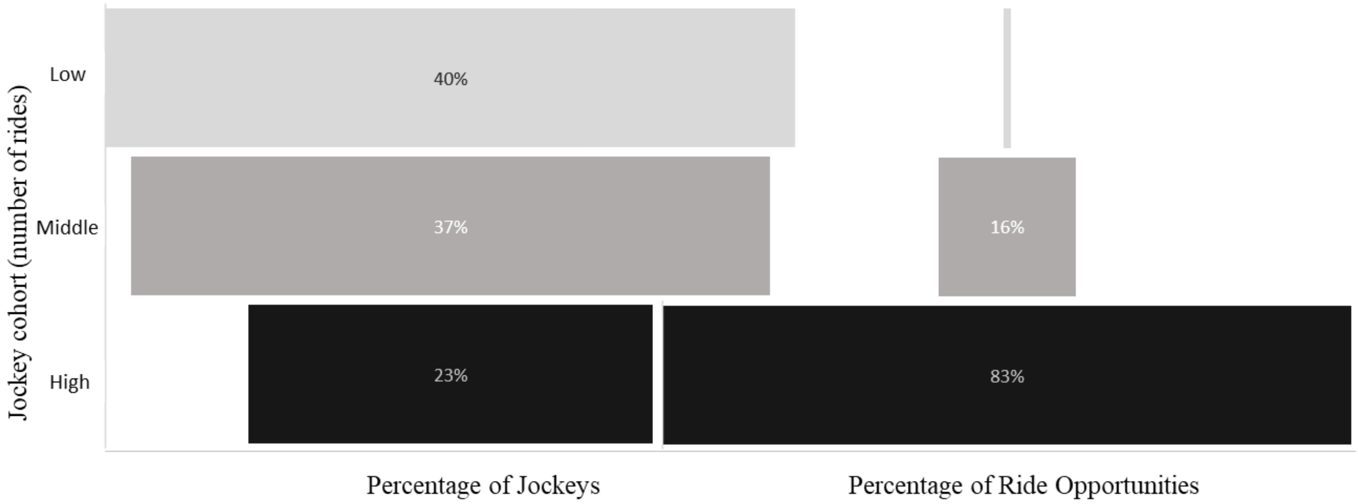

Figure 3.2 Percentages of flat racing jockeys and total number of flat racing rides for low (1 - 10), middle (10 - 200) and high (> 200 rides per season) workload cohort jockeys from 1 August 2005 - 17 April 2019.

There was a median of 59 (IQR 56 - 63) flat racing jockeys in the high workload cohort each season (Figure 3.3), with a median of 13 (IQR 10 - 14) jockeys entering and 14 (IQR 11 - 16) jockeys leaving the high workload cohort each season. The total number of rides by these jockeys was highest in the 2009/10 season (n = 28,079, median 406, IQR 304 -543), but subsequently decreased linearly by 910 rides per season (R^2 = 0.9).

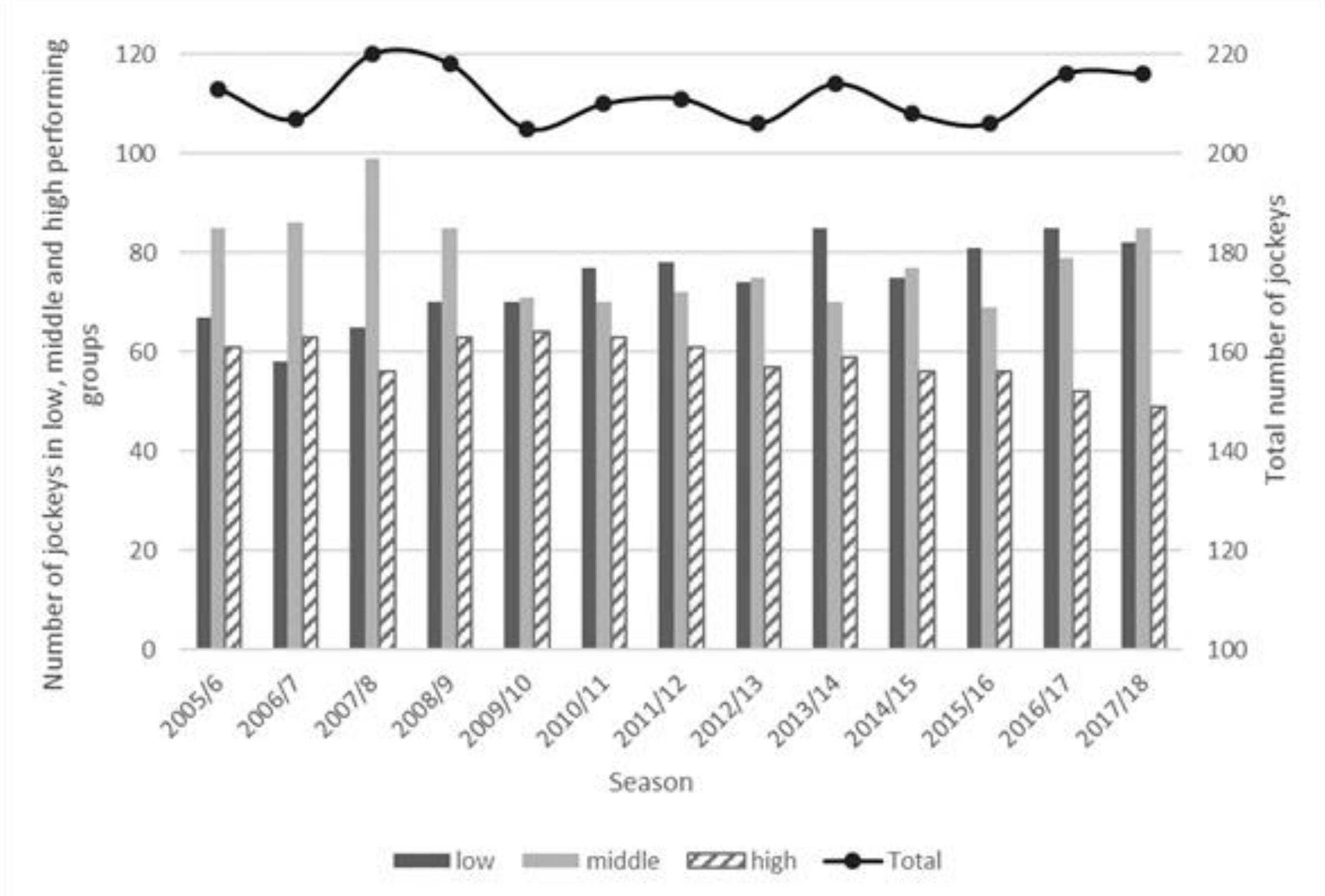

Figure 3.3 Numbers of flat racing jockeys in low (1 - 10), middle (10 - 200) and high (> 200 rides per season) cohorts from 1 August 2005 – 17 April 2019.

There was a median of 77 (IQR 71 - 85) flat racing jockeys in the middle workload cohort and 75 (IQR 69 - 82) flat racing jockeys in the low workload cohort each season (Figure 3.3). The majority of jockeys in each of these groups changed each season, with less than half the jockeys remaining for more than one season in either cohort.

3.6 Discussion

This study provides a unique starting point to understanding the jockey 'athlete' workload. Most jockeys and apprentices rode in flat races, with opportunities year-round, and no off-season. There was a large proportion of jockeys who rode very few race days per season, indicating that the majority of jockeys had a very light and sporadic workload, lasting only 1 -

3 years. This suggested that there was an excess of jockeys competing for the fixed number of ride opportunities. This disequilibrium in ability to compete has implications for the recruitment of new participants to the industry and sustainability of the workforce.

Jockeys with low racing workloads likely supplement their work as jockeys with extra track-work (daily exercise of racehorses) or stable-hand duties, as occurs with failed apprentices in Britain (Kiely *et al.*, 2020; Vamplew, 2016). Due to their low workload, they are likely also to be inexperienced in race day riding, which has been linked to lower horse performance (Hitchens *et al.*, 2010; O'Connor *et al.*, 2018). It has been identified that riding a race is more physically demanding than riding daily track-work (Kiely *et al.*, 2019) and jockeys rarely participate in additional off-horse physical training regimes except as a measure to reduce weight (Dolan *et al.*, 2011; Kiely *et al.*, 2020; Leydon *et al.*, 2002). The higher incidence rate for falls in the low workload cohort indicates that if these jockeys are not partaking in sufficient extra physical training, or competition-specific exercise, they may not be physically or mentally prepared to meet the demands of riding in a race. The higher rate of falls predisposes them to greater injury risk, subsequent time out of racing, and this lack of physical and mental preparation would limit race success. The compounding of these factors with reduced competition-specific exercise in addition to inexperience, may explain, in part, the much greater rate of loss of athletes from this cohort.

Workload for flat racing jockeys varied more than for apprentices who had a more consistent seasonal workload. This may have been due to the weight allowance apprentices claim, giving them an advantage over jockeys in securing rides (horses carrying less than their assigned weight have an advantage). However, apprentices still had fewer rides per race-day than jockeys, which could be a recognition by the trainers who secure their rides of their lack of experience and physical preparedness to compete at the level of the high workload cohort of jockeys with multiple races per race-day. Indeed, jumps racing apprentices had a significantly lower workload than jockeys, indicating that their weight advantage may not be as important as the experience of the fully licensed jockey in the longer and more demanding race.

Apprentices in their ultimate year of apprenticeship were more likely to have a higher number of rides per season than in their first-year riding as a jockey, though the difference was not significant. Apprentices have trainer support to secure rides, in addition to having a weight allowance, both of which are lost when they become jockeys. The loss of these bonuses may make the transition into professional sport difficult, resulting in a lighter workload during their first professional jockey year than during their apprenticeship. Industry support for apprentice jockeys moving out of their apprenticeship may facilitate a greater proportion of jockeys moving more successfully into professional sport.

3.6.1 High workload cohort jockeys

The workload of the relatively small group of jockeys in the high workload cohort was higher than that of the majority of jockeys, and this bias is similar to findings in Australia and the USA (Press *et al.*, 1995; Speed, 2001). However, the workload of these New Zealand jockeys, riding competitively twice weekly, was less than that qualitatively reported for Britain (Dolan *et al.*, 2011; Kiely *et al.*, 2020; Warrington *et al.*, 2009). This could be due to the higher number and greater geographical concentration of races in Britain, providing more riding opportunities.

During their career, jockeys in the high workload cohort spent little time riding fewer than 200 rides per season, with minimal exchange in and out of this group with the low and middle workload cohorts. Similar to that observed in other sports such as baseball (Witnauer *et al.*, 2007), a successful jockey's career appears to be characterised by a rapid ascent and decline in workload (ride numbers), demonstrating a compressed work career. In addition, these jockeys were successfully able to meet low riding weights, indicating an ability to maintain a consistent bodyweight year-round. Time spent by high-performing jockeys in the middle and low workload cohorts may reflect time off due to injury or ride infringements. However, this information was not included in the dataset.

The large numbers of jockeys competing for a fixed number of ride opportunities, results in high selectivity for the jockeys able to perform at a high level. Jockeys in all cohorts began race riding in their 20s. In North American professional sports, there is an age specific range of maximum performance (Steingröver *et al.*, 2016; Witnauer *et al.*, 2007), and this age may enable them to meet the physical demands of horse racing more successfully and for longer than those beginning at a later age. These data indicate that there may be an optimal number of race rides required to maintain the competition-specific fitness and conditioning required to compete safely and successfully in this sport. Prospective research is required to identify this threshold. Early selection of and support for candidates who are able to join this high workload cohort would reduce risk to both horse and jockey and loss of athletes from the sport.

Both an athlete’s total workload and chronic workload (changes in load over time) are related to injury risk, with spikes in activity resulting in higher likelihood of injury and high chronic workloads associated with lower injury risk (Windt *et al.*, 2017). The consistent flat racing schedule observed in New Zealand allows continuous opportunities for jockeys to compete and minimizes the risks of spikes in workload. However, jumps races are seasonal, and this may, in part, contribute to the higher rate of falls by jumps racing jockeys. Any greater risk of a fall in jumps racing due to “lack of practice” is further exacerbated by the greater inherent risk of a fall in jumps racing due to longer races and therefore greater time spent at risk, as well as the nature of jumping a fence during a race, increasing the chance of a jockey becoming unseated (Hitchens *et al.*, 2009; Legg *et al.*, 2019; McManus *et al.*, 2014). The majority of jumps jockeys compete sporadically and do not have a sufficient workload to prepare them for them for the higher levels of the sport without additional physical training.

Lack of conditioning may not only be an obstacle to a jockey's progression in the industry but an important factor in their risk of falling from the horse and thus potentially sustaining career ending injuries (Hitchens *et al.*, 2011; Hitchens *et al.*, 2012; Legg *et al.*, 2020). This observational study provides an initial external workload from which further research is required to understand the current level of training (internal and external workloads) undertaken by apprentices and jockeys and to determine whether it is sufficient to meet the demands of the sport. These data are required in the formation of a physical conditioning programme to optimally prepare the jockey for their demanding race schedules and reduce potential injury risk.

3.6.2 Limitations

This study was based on retrospective data and thus the analysis was restricted to variables that could be quantified with this data. There are a number of factors which may influence or limit a jockey's workload and career, such as lack of talent, struggles with weight restriction and injury. To quantify the effect of these, a prospective study and access to data outside the scope of this project are required. In some cases, data are presented as summative cases across years and there may be some individuals who are initially represented as apprentices and subsequently as jockeys as they progress through their career. The collection of data across 14 seasons should ameliorate this limitation to some extent.

3.7 Conclusions

The external workload of flat racing jockeys was higher than for jumps racing jockeys. The majority of flat racing jockeys had a very light seasonal workload of fewer than 14 races per season and rode for two years. These data indicate an inability to obtain sufficient rides to develop, let alone sustain, a viable career as a jockey. Compounding this, these jockeys were associated with a greater risk of falling (and thus injury) and less success than jockeys with higher workloads, which may be due to lack of "race day specific" conditioning and experience (skill). A small number of jockeys were responsible for the majority of flat racing starts, rode at consistently low weights and rode for 6 years or more, indicating that they were able to maintain competition-specific fitness levels to enable successful performance in their sport. This study provides a unique foundation in understanding the jockey's 'athlete' workload, the importance of which has ramifications for the jockey's career, both in terms of success and injury prevention.

3.8 References

Bergmann, I. (2019). Interspecies sustainability to ensure animal protection: Lessons from the Thoroughbred racing industry. *Sustainability,* 11(19). doi:10.3390/su11195539

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science,* 56(1): 77- 81. doi:10.1071/an13442

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., . . . Cable, N. T. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sport Physiology and Performance,* 12(Suppl 2): S2161-S2170. doi:10.1123/IJSPP.2017-0208

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Science,* 29(8): 791-799. doi:10.1080/02640414.2011.560173

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011). Are physiological attributes of jockeys predictors of falls? A pilot study. *BMJ Open,* 1(1): e000142. doi:10.1136/bmjopen-2011-000142

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L., & Fell, J. (2010). Predictors of race-day jockey falls in flat racing in Australia. *Occupational and Environmental Medicine,* 67(10): 693-698. doi:10.1136/oem.2009.050567

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2009). The incidence of race-day jockey falls in Australia, 2002–2006. *The Medical Journal of Australia,* 190(2): 83-86. doi:10.5694/j.1326-5377.2009.tb02284.x

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2012). The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention,* 18(6): 385-391. doi:10.1136/injuryprev-2011-040255

IER. (2018). *Size and Scope of the New Zealand Racing Industry* New Zealand Racing Board: https://www.nzrb.co.nz/sites/default/files/documents/NZ%20Racing%20Size%20and%20Scope%202018%20Full%20Report.pdf. Accessed on Dec 2019

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. J. (2020). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi:10.1519/JSC.0000000000003514. Epub ahead of print.

Kiely, M. A., Warrington, G. D., McGoldrick, A., O'Loughlin, G., & Cullen, S. (2019). Physiological demands of daily riding gaits in jockeys. *Journal of Sports Medicine and Physical Fitness,* 59(3): 394-398. doi:10.23736/S0022-4707.18.08196-3

Legg, K. A., Breheny, M., Gee, E. K., & Rogers, C. W. (2019). Responding to risk: Regulation or prohibition? New Zealand media reporting of Thoroughbred jumps racing 2016–2018. *Animals,* 9(5): 276. doi:10.3390/ani9050276

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport,* 23: 1154-1160. doi:https://doi.org/10.1016/j.jsams.2020.05.015

Leydon, M. A., & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12: 220-237.

McManus, P., Graham, R., & Ruse, K. (2014). The construction of human-animal relations: National Jumps Day 2013 at Te Rapa, Hamilton, New Zealand. *New Zealand Geographer,* 70(3): 190-200. doi:10.1111/nzg.12068

New Zealand Thoroughbred Racing. (2019). *Handicapping guide*. Wellington, New Zealand: https://loveracing.nz/OnHorseFiles/LoveRacing/Articles/2018/2019%20Handicappin g%20Policy%20(Effective%20from%201%20August%202019).pdf. Accessed: Jan 2020

O'Connor, S., Warrington, G., Mb, A. M., & Cullen, S. (2018). A 9-year epidemiologic study (2007-2015) on race-day jockey fall and injury incidence in amateur Irish horse racing. *Journal of Athletic Training,* 53(10): 950-955. doi:10.4085/1062-6050-339-17

O'Reilly, J., Cheng, H. L., & Poon, E. T.-C. (2017). New insights in professional horse racing; "in-race" heart rate data, elevated fracture risk, hydration, nutritional and lifestyle analysis of elite professional jockeys. *Journal of Sports Sciences,* 35(5): 441-448. doi:10.1080/02640414.2016.1171890

Pfau, T., Spence, A., Starke, S., Ferrari, M., & Wilson, A. (2009). Modern riding style improves horse racing times. *Science,* 325(5938): 289. doi:10.1126/science.1174605

Press, J. M., Davis, P. D., Wiesner, S. L., Heinemann, A., Semik, P., & Addison, R. G. (1995). The national jockey injury study: an analysis of injuries to professional horse-racing jockeys. *Clinical Journal of Sport Medicine,* 5(4): 236-240.

Ruse, K., Davison, A., & Bridle, K. (2015). Jump horse safety: reconciling public debate and Australian Thoroughbred jump racing data, 2012-2014. *Animals,* 5(4): 1072-1091. doi:10.3390/ani5040399

Speed, H., Seedsman, T., Morris, T., and Sullivan, R. (2001). *The welfare of retired jockeys.* Melbourne: Victoria University of Technology, Centre for Rehabilitation, Exercise and Sports Science.

Steingröver, C., Wattie, N., Baker, J., & Schorer, J. (2016). Does relative age affect career length in North American professional sports? *Sports Medicine Open,* 2(18). doi:10.1186/s40798-016-0042-3

Trowbridge, E. A., Cotterill, J. V., & Crofts, C. E. (1995). The physical demands of riding in National Hunt races. *Eurupean Journal of Applied Physiology,* 70(1): 66-69.

Vamplew, W. (2016). Still crazy after all those years: continuity in a changing labour market for professional jockeys. *Sport in Society,* 19(3): 378-399. doi:10.1080/17430437.2015.1059015

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

Windt, J., & Gabbett, T. J. (2017). How do training and competition workloads relate to injury? The workload-injury aetiology model. *British Journal of Sports Medicine,* 51(5): 428-435. doi:10.1136/bjsports-2016-096040

Witnauer, W. D., Rogers, R. G., & Saint Onge, J. M. (2007). Major league baseball career length in the twentieth century. *Population Research and Policy Review,* 26(4): 371-386. doi:10.1007/s11113-007-9038-5

4 Chapter Four - Jockey career length and risk factors for loss from Thoroughbred race riding

Published in part in the following publication.

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2020). Jockey career length and risk factors for loss from Thoroughbred race riding. *Sustainability*, 12(18). doi:10.3390/su12187443

4.1 Foreword to Chapter Four

The previous chapter showed that there was an imbalance within the industry with a small number of jockeys accounting for the majority of race rides. It demonstrated that jockeys with higher competitive workloads had lower injury risk and greater racing success than jockeys with lower workloads, provoking the question – are they physically fitter? A disparity in opportunity and success between cohorts indicated inefficiencies within the industry in recruitment and retention of jockeys. Due to the high physiological demands of racing, and ubiquitous requirement to maintain both racing fitness and a low body mass year-round, the impact of high or low jockey competitive workloads on jockey career longevity was unknown. Therefore, the next step in this research was to examine the career length of jockeys and risk factors for loss of jockeys from the New Zealand Thoroughbred racing industry.

4.2 Abstract

Professional Thoroughbred racing jockeys repeatedly work close to physiological capacity during races, whilst maintaining low body weights, on a daily basis with no off-season. The effects of this on their career length is unknown. The aim of this study was to examine the career lengths and reasons for loss from the industry of 674 jockeys and apprentices who rode over 14 racing seasons, and 421,596 race day starts in New Zealand. Descriptors were compared between jockeys in short (1 - 2 years), middle (3 - 9 years) and long (> 10 years) career cohorts with descriptive statistics and Kaplan–Meier survival curves. The median career length for jockeys was 2 years (IQR 1 - 6). Long career cohort jockeys (11%) had lower carried weights (IQR 56 - 57 kg, $p = 0.03$), 40 times the median number of rides per season (248, IQR 61 - 434, $p < 0.001$), half the rate per 1,000 rides of falling (1.1, 95% CI 1.0 - 1.2, $p = 0.009$) and 1.3 times the rate of winning (100, 95% CI 99 - 101, $p < 0.01$) than jockeys in the short career cohort. Jockeys who rode over 200 races per season had careers three times longer than jockeys with fewer races per season ($p < 0.001$). Half of the 40% of jockeys who failed to complete their apprenticeship were lost from the industry in their first year of race riding. In conclusion, most jockeys had short careers where the workload of a jockey and their ability to obtain rides had greater impact on career longevity than their performance.

4.3 Introduction

Thoroughbred racing is a major international sport in which jockey and horse work together, racing at speeds exceeding 60 $km \cdot h^{-1}$ (Warrington *et al.*, 2009). During races, the jockey is positioned over the withers of the horse in a crouched forward stance, in a state of continuous quasi-isometric movement - an activity that is extremely physically demanding. Jockeys exercise close to their physiological capacity during a race (Cullen *et al.*, 2015; Trowbridge *et* *al.*, 1995). At the same time, in order to meet the weight allocated to the horse to carry during a race, they have to maintain consistently low body mass year-round (Warrington *et al.*, 2009).

Professional jockeys may ride in flat or jumps races. Flat races are shorter than jumps races, occur year-round and comprise 96% of the total number of races in New Zealand, whereas jumps (hurdle and steeplechase) races occur only during the winter season and include up to 25 obstacles (Bolwell *et al.*, 2016). Races in New Zealand operate with minimum riding weights, facilitated by a handicapping system to enable equal competition, based on ratings assigned to each horse. Rating (flat, hurdles or steeples) is a dynamic measure of a horse's performance and is recalculated within two days of a horse's most recent race start. Higher rated (better performing) horses are assigned higher weights (New Zealand Thoroughbred Racing, 2019). At present, minimum riding weights of 52 kg and 63 kg are in operation for flat and jumps jockeys respectively, with the option for inexperienced (apprentice) jockeys to claim an allowance of 1 - 4 kgs depending on previous wins (New Zealand Thoroughbred Racing, 2019).

The workload of professional jockeys is high. In New Zealand, Australia and Ireland, jockeys ride in one to eight races a day, in two to four race-days a week, with no off-season (Dolan *et al.*, 2011; Leydon *et al.*, 2002; Speed, 2001). In the United Kingdom (UK) and United States (USA) a jockeys' workload can be greater, with races occurring up to 7 days a week (Press *et al.*, 1995; Warrington *et al.*, 2009). Jockeys have the added risk of falling from the horse, with incidence rates (per 1,000 starts) of 1.2 for flat and 53 - 100 for jumps racing (Legg *et al.*, 2020), increasing the potential for injury and confidence loss for jockeys. The effects of a consistently high workload, maintaining a low body mass year-round and the high potential for injury on potential career length of jockeys are unknown.

Although the careers of Thoroughbred racehorses have been extensively studied (Jeffcott *et al.*, 1982; Sobczyńska, 2007; Tanner *et al.*, 2013), little is known about the career prospects of the jockeys that ride them. Retrospective questionnaires answered by current professional jockeys in USA, Korea, Ireland and Australia indicate that jockey career lengths are 10.9 - 15.9 years (Dolan *et al.*, 2011; Jeon *et al.*, 2018; Kiely *et al.*, 2020), with a strongly skewed distribution toward the lower end of the scale (Press *et al.*, 1995; Speed, 2001). However, these findings may be biased upwards because the studies only targeted jockeys who were found at the racetrack at the time of questioning. By default, this would include higher proportions of well-established jockeys who had secured a race day ride.

Whilst it is common for professional athletes in many sports to retire due to injury (Baker *et al.*, 2013; Witnauer *et al.*, 2007), in the sport of horse racing, jockeys leave their profession for a number of reasons, such as lack of rides, weight gain, injury, loss of confidence and competency (Press *et al.*, 1995; Speed, 2001; Vamplew, 2016). Since little is currently known about the career length of jockeys in the Thoroughbred industry, the aim of this study was to determine the career lengths and risk factors for loss from the industry of Thoroughbred racing jockeys in New Zealand. This information would be beneficial in determining the costs and benefits to the jockey of riding more races, and to the industry in optimising the selection and preparation of apprentices to fulfil the need for quality jockeys who can have long and successful careers. It was hypothesised that jockeys with longer careers would have more rides, fall less often and have more success than shorter career jockeys.

4.4 Materials and methods

Data from all Thoroughbred race-starts between 1 August 2005 and 17 April 2019 were supplied by New Zealand Thoroughbred Racing (NZTR), the governing body for Thoroughbred racing in New Zealand. A racing season began on the 1 August and ended on the 31 July. Data were provided at the ride level and the following variables were extracted and used for further analysis: date of race; horse carried and assigned weight and domestic rating; jockey name, gender and age; race outcome (in the form of jockey falls or wins). Hurdle and steeplechase races were combined into one category of jumps races, to allow comparison between flat and jumps races.

Carried weight refers to the weight carried by the horse during the race. For the purposes of this study, an apprentice was defined as a rider whose horses carried weight was ≤ 1 kg from the handicap weight assigned to the horse, whereas a jockey rode at the assigned horses' weight. Three evenly populated workload cohorts of 'low', 'middle' and 'high' were created based on the number of rides each jockey rode per season. For flat and jumps racing respectively, those who rode 1 - 10 or 1 - 5 rides per season were assigned to the low cohort, jockeys who rode 10 - 200 or 5 - 25 rides per season were assigned to the middle cohort and jockeys who rode over 200 or 25 rides per season were assigned to the high cohort. Career length cohorts of 'short', 'middle' and 'long' were created based on the time between the first and last race ride of a jockey. Jockeys with careers of 1 - 2 (i.e., less than 3) years were assigned to the 'short' cohort, jockeys with careers of ≥ 3 - 9 years were assigned to the 'middle' cohort and jockeys with careers of more than 10 years were assigned to the 'long' cohort. Analyses were conducted on flat racing jockeys only, except where jumps racing jockeys were used as a comparison group. Jockeys who were not licensed in New Zealand (n = 112) were removed from the data.

The integrity of the data were checked using histograms, scatter plots and box plots, where outliers or points of interest were compared with the official NZTR database. Descriptive statistics were used to describe the data at population level for the career length cohorts. Counts and percentages were used to describe categorical data and median and interquartile range (IQR) were used to describe continuous data that were non-normally distributed. Incidence rates were calculated based on the number of falls or wins and number of rides during the time period and expressed as a rate per 1,000 rides. Kaplan–Meier survival curves were used to estimate jockey career lengths, based on the dates of their appearances in the data set. Linear regression was used to calculate rates of survival probabilities. Seasonal trends were analysed using seasonal and trend decomposition using loess (STL) plots and box plots. Normality was assessed using an Anderson–Darling test and Kruskal–Wallis tests for significance were used to compare differences between groups.

Analyses were conducted in RStudio (version 3.5.1, 2018; R Foundation for Statistical Computing, Vienna, Austria) with the level of significance set at $p < 0.05$.

4.5 Results

During the period 1 August 2005 - 17 April 2019 there were 37,596 flat races over 4,459 race days and 1,528 jumps (897 hurdle and 631 steeple) races over 536 race days. There was a total of 421,596 ride opportunities, of which 407,948 were flat racing starters and 13,648 jumps racing starters.

Data were collected on 674 jockeys and apprentices licensed in New Zealand, the majority of which (97%) rode in flat races and only 24% rode in a jumps race. Male jockeys accounted for 58% of the total number of registered jockeys or apprentices over the study period. The distribution of career length was highly positively skewed (Figure 4.1). The median career length of all jockeys was two (IQR 1 - 6) seasons, with no differences in rate of loss of jockeys between race type (flat or jumps, p = 0.5). After the first year, the rate of loss of female jockeys was higher than for male jockeys (p = 0.006). Jockeys who began their careers under 18 years of age were twice as likely to remain in their career than jockeys who began at an older age (p = 0.02). Twenty-four (4%) jockeys rode for all 14 race seasons.

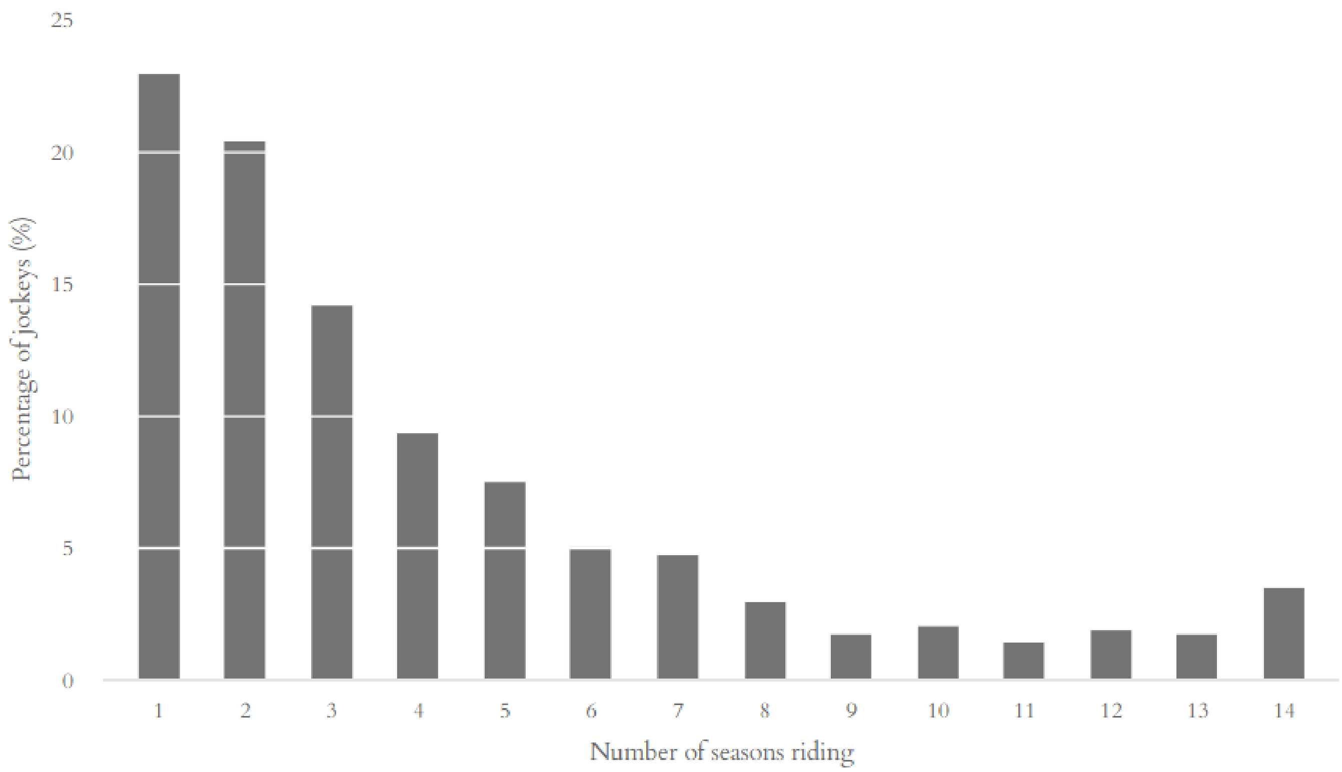

Figure 4.1 Number of seasons riding for flat and jumps racing jockeys for the 2005/6 - 2018/9 racing seasons.

Jockeys in the long career length cohort (11%) were more likely to be male and had more rides and wins per season than jockeys in the short (43%) and middle (46%) career length cohorts (Table 4.1). Jockeys in the short career cohort had twice the incidence rate of falls and were less likely to ride a winner than jockeys in the high career length cohort.

Table 4.1 Characteristics of flat racing jockeys with short (1 - 2 years), middle (3 - 9 years) and long (>10 years) career lengths for the 2005/6 - 2018/9 racing seasons.

Descriptor	**Short**	**Middle**	**Long**	**p value**
	Number of observations (%)			
Female	120 (42%)	133 (44%)	16 (23%)	
Male	152 (54%)	168 (55%)	54 (77%)	0.001
	Median (IQR)			
Age at first appearance (years)	25 (22 - 31)	23 (20 - 27)	25 (21 - 31)	<0.001
Average carried weight (kg)	56 (54 - 67)	56 (54 - 64)	56 (56 - 57)	0.03
Average flat rating	61 (57 - 65)	61 (59 - 63)	62 (61 - 64)	0.03
Rides per season	6 (2 - 18)	44 (10 - 136)	248 (61 - 434)	<0.001
Wins per season	0 (0 - 1)	2 (1 - 11)	18 (4 - 43)	<0.001
Total number of falls	0 (0 - 0)	0 (0 - 1)	3 (1 - 5)	<0.001
Total number of wins	0 (0 - 2)	10 (2 - 50)	221 (50 - 558)	<0.001
	Incidence Rate (95% CI)			
Falls/1000 rides	1.9 (1.3 - 2.8)	1.3 (1.1 - 1.5)	1.1 (1.0 - 1.2)	0.009
Wins/1000 rides	75 (71 – 80)	84 (83 – 86)	100 (99 – 101)	<0.001

The total number of falls and wins experienced by a jockey increased with career length. There was no difference between the median time (456 days, IQR 174 - 880) and number of rides (239, IQR 66 - 508) from the beginning of a flat racing jockey's career to their first race-day fall and the time (715 days, IQR 277 - 1460, p = 0.6) and number of rides (226, IQR 62 - 738, p = 0.6) from their last race-day fall until the end of their career for flat racing jockeys from all cohorts. There was a non-significant trend for both time and number of rides before (p = 0.5) and after (p = 0.7) first and last race-day fall to be greater for longer career lengths.

The median career length of flat racing jockeys who had more than one fall over their career (n = 58) was more than 14 years, with a low linear rate of loss (4% per season, $R^2 = 0.9$). This was longer than the median career length of jockeys with one fall (5 years, n = 92) or no falls (1.5 years, n = 507, $p < 0.001$).

Similar to falls, the total number of wins by a jockey increased with career length. There was no difference between the median time (44 days, IQR 8 - 214) and number of rides (8 rides, IQR 3 - 18) from the beginning of a flat racing jockey’s career to their first race-day win and the time (42 days, IQR 7 - 280, p = 0.1) and number of rides (10, IQR 4 - 19, p = 0.3) from their last race-day win until the end of their career for flat racing jockeys from all cohorts ($p > 0.05$). There were no differences between career length cohorts from time until first win, and from last win until end of careers.

Career length and rate of loss from the industry was strongly associated with the number of rides ridden by a flat racing jockey during a season (Figure 4.2). Approximately four (5%) high workload cohort jockeys (n = 78) left the sport each season resulting in a median career of 10 seasons, over threefold longer than observed for jockeys from low and middle workload cohorts (two to three seasons). This was similar for jumps racing, where high workload cohort jockeys (n = 26) had median careers of 6 years and approximately two jockeys (8%) leaving each season, twice as long as those in the middle workload cohort (n = 56), and three times as long as jockeys in the low workload cohort (n = 77, $p < 0.001$), both with exponential rates of loss.

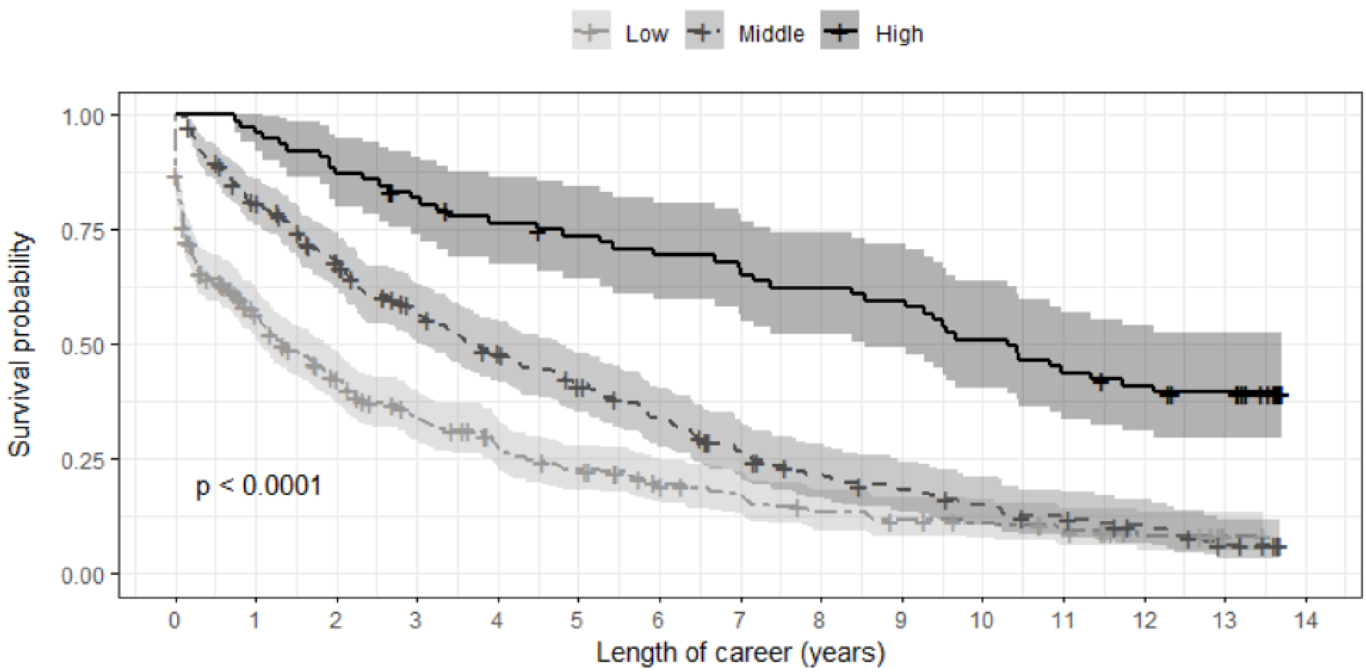

Figure 4.2 Length of career of flat racing jockeys who first appear in low (1 - 10 rides/season, n = 335), middle (10 - 200 rides, n = 244) or high (>200 rides, n = 78) workload cohorts for the 2005/6 - 2018/9 racing seasons. Shaded area indicates 95% confidence interval.

4.5.1 Apprentices

There was a difference in career length for those jockeys who completed their apprenticeship and those who did not (Figure 4.3). Only 40% (131/331) of apprentices completed their apprenticeship training. Half of the jockeys who did not complete their apprenticeship during the time period were lost within a year of their first race day ride. For those who did complete their apprenticeship, their median career length was 6.5 years. For the 32% of jockeys who continued to ride for more than 7 years, the linear rate of loss slowed by half (8% to 3% per year, $R^2 = 0.97$).

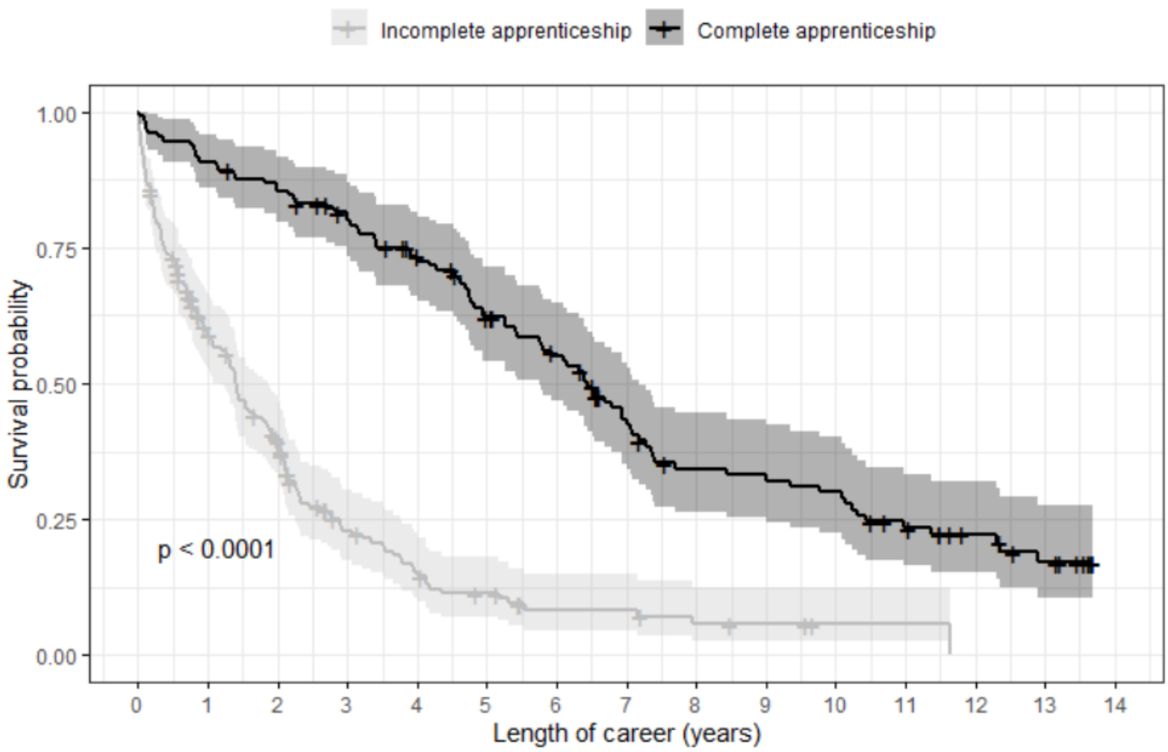

Figure 4.3 Career survival probability for apprentices that completed their apprenticeship (n = 131) and those that did not (n = 200) for the 2005/6 - 2018/9 racing seasons. Shaded area denotes 95% confidence interval.

4.5.2 Yearly racing

Race opportunities were available year-round, but there were more horses flat racing in the summer (October - January) than in winter months (June - September) (Figure 4.4). The rides of jockeys in the high workload cohort followed this seasonal trend, with two seasonal peaks in ride numbers in December (summer) and April (autumn), respectively, of 1.7 times and 1.5 times the month with the least number of rides in August (winter). Apprentices also had two seasonal peaks in ride numbers in December and May of 1.5 and 1.7 times that of the number of rides in February, the month in which they had the least number of rides. Jockeys in the middle workload cohort had two seasonal peaks in ride numbers in May–July and November–January of 2.2 and 1.5 times the number of rides in February, when they had least rides.

Jockeys in the low workload cohort had only one seasonal peak in ride numbers, riding twice as many races from November–January than in April–July.

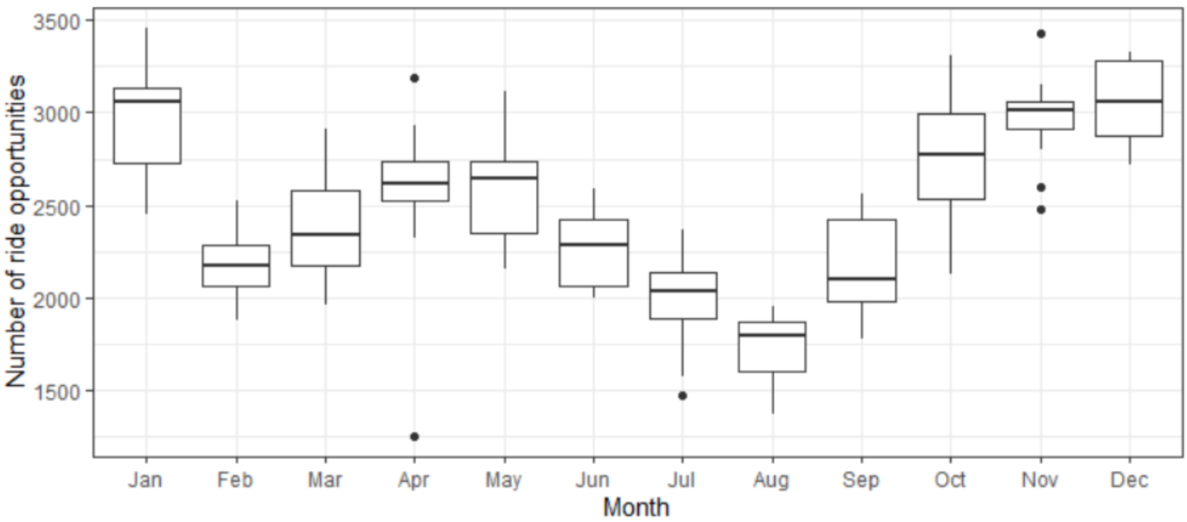

Figure 4.4 Number of monthly flat racing ride opportunities for the 2005/6 - 2018/9 racing seasons

Apprentices rode in a higher proportion of races during the winter months than the summer months. Jockeys from the high workload cohort rode the majority of two-year-old races year-round compared with apprentices or jockeys in the low and middle workload cohorts.

4.6 Discussion

This study provides new information documenting the career lengths and reasons for loss from the industry for Thoroughbred racing jockeys in New Zealand. The career length of the majority of jockeys in New Zealand was short (< 3 years), and similar for both flat and jumps racing jockeys. A higher workload (in terms of number of races ridden) was positively associated with the career length of jockeys in New Zealand. Similar findings have been previously reported in qualitative studies in Australia and UK, where lack of rides was reported to be the major limiting factor for most jockeys' careers (Speed, 2001; Vamplew, 2016). This indicates there is a surplus number of jockeys than is required by the available ride opportunities.

Jockeys who had high workloads in the current study had similar career lengths to jockeys in USA, Korea and Australia of 10 - 15 years (Jeon *et al.*, 2018; Kiely *et al.*, 2020; Press *et al.*, 1995; Speed, 2001). The data set used in the current study was a cross-section of 14 seasons, that may erroneously group jockeys at the start and end of their careers into lower career cohorts and does not record the length of careers which span for more than 14 seasons. This effect was considered minimal due to the consistency of the trends over the data set and similarity of career lengths with jockeys from other jurisdictions. Though there were relatively even numbers of male and female jockeys entering the industry, the rate of loss of female jockeys was higher, indicating that longer career jockeys were more likely to be male.

4.6.1 Long career cohort jockeys

Jockeys with longer careers were less likely to fall during a race and more likely to ride a winner than jockeys with shorter careers, indicating that they ride more safely and more successfully than their counterparts. However, those with longer careers had a higher total number of falls and the rate of loss of jockeys with more than two falls over the length of their career was low. This indicates that falling (and the cumulative frequency thereof) may not be a driver of career longevity and performance for flat racing jockeys. In addition, the lack of association between time or number of rides until the first fall or win of a jockey and between their last fall or win and the end of their career indicates that neither falling nor winning was a driving factor for career length. Thus, the higher number of falls by longer career jockeys may be a simple reflection of the greater time spent at risk. The higher total number of wins by longer career jockeys would increase their status and enable them to more easily obtain future rides, thereby prolonging their career. This view was supported by the observation that longer career jockeys rode horses with higher ratings indicating that they were able to attain higher quality rides with more chance of success.

Although longer career jockeys fell less often than shorter career jockeys, as a group they had more falls. Injury has previously been identified as one of the factors for jockeys ending their careers (Speed, 2001; Vamplew, 2016). For example, Korean flat racing jockeys with an average career span of 11.6 years reported at least one injury, most occurring during practice or competition and due to difficulties in handling horses, though it was unclear if this was whilst riding or ground handling horses (Jeon *et al.*, 2018). In the UK, half of the accidents reported in racehorse stables were from falling from a horse during training (Filby *et al.*, 2012). Although falls occurring pre- and post-race, or during trackwork and training were not taken into account in the present study, falls occurring during a race are more likely to result in injury to the jockey (Curry *et al.*, 2016; Waller *et al.*, 2000) and account for approximately half of jockey race day falls in New Zealand (Bolwell *et al.*, 2014). In addition, despite having fewer racing opportunities, jumps racing jockeys fall during the race 50 - 100 times more often than flat racing jockeys (or once every 10 - 20 races) (Legg *et al.*, 2020). Thus, falling from a horse is a major risk, not only during a competitive race, but also during training activities. For these reasons, training on how to fall safely early in a jockey's career may help to reduce the risk of injury from falling from a horse.

In the current study, long career cohort jockeys rode at a smaller range of carried weights compared to short and middle career length cohorts. The year-round ride opportunities require jockeys to be able to meet these riding weights consistently, and inability to meet the weight requirements has been identified as limiting jockey careers in Australia and USA

(Speed, 2001; Vamplew, 2016). Therefore, the ability to make weight may be an important driver for racing success.

Jockeys have been found to be smaller, lighter, have better balance and reaction times, greater anaerobic and aerobic fitness and greater muscular strength and power than track riders who exercise racehorses daily (Hitchens *et al.*, 2011a). Therefore, factors such as jockey phenotype, fitness, or work ethic (mental stamina) may be more important predictors of jockey success/longevity than racing performance. These factors may be apparent early on in a jockey's career, as shown by the high rate of loss of non-graduating apprentices after just 6 months. This may underline the importance of a pre- selection criteria early in a jockeys' career, as occurs in other sports (Baker *et al.*, 2013), to identify candidates who are most likely to be successful as jockeys. Thus, future studies should investigate the optimal physical characteristics of jockeys in order to maximise 'talent' potential.

4.6.2 Apprentices

The current results revealed that jockey apprenticeship programmes had a high rate of loss (40%), half of which was within a year of their first race day ride. This was lower than observed in UK, with the director of the British racing school in 2000 estimating that 9 out of 10 apprentices failed to become full professional jockeys (Vamplew, 2016). In the present study, the median combined (apprenticeship and jockey) career length of graduating apprentices of 6 - 7 years indicated that additional investment into early careers of jockey may be beneficial to increase workforce retention. This has been shown to be effective; a structured training programme was introduced to apprentices in Victoria, Australia in 1992 and reduced the numbers of the annual apprentice intake that failed to become jockeys from 25% to 10% (Speed, 2001). Therefore, appropriate industry changes can improve jockey retention and possibly career length in the industry. Having rigorous selection criteria and decreasing the apprentice intake may allow more intensive investment into the training and education of new apprentices. In association with a specialised apprentice training programme, these measures may help to retain and support jockeys in their career.

4.6.3 Seasonal rides

The current analysis revealed a seasonal trend in ride opportunities for jockeys, with more rides during spring carnival racing, and in autumn, where there is a cross over with 'winter' horses commencing work, and 'summer' horses finishing their season.

High workload cohort jockeys had their highest number of races during spring and summer racing, when most of the high-stakes races occur, and 2-year-olds are introduced to racing. Proportionally more licensed and high workload cohort jockeys rode in 2-year-old races, indicating that a new and inexperienced horse with unknown potential was given the best possible chance of winning by having a more experienced rider. The summer peak in ride numbers by low workload jockeys may reflect the extra rides they are able to acquire due to the higher number of ride opportunities in summer. Interestingly, the peak for the middle workload cohort jockeys and apprentices was highest in autumn, indicating that these jockeys may ride more of the (slower) 'winter' racing horses, or experienced horses at the end of the summer racing season. As inexperienced jockeys and inexperienced horses have both been found to be risk factors in jockey falls (Hitchens *et al.*, 2011b; Hitchens *et al.*, 2010; Legg *et al.*, 2020; O'Connor *et al.*, 2018), this is an interesting finding which indicated the industry is actively protecting the interests of the less experienced jockeys, giving them valuable race experience in potentially slower races.

The large numbers of jockeys competing for a fixed number of ride opportunities, results in high selectivity for the high performing jockeys. It has been identified that riding a race is more physically demanding than riding daily trackwork (Kiely *et al.*, 2019) and jockeys rarely participate in additional off-horse physical training regimes except as a measure to reduce weight (Dolan *et al.*, 2011; Leydon *et al.*, 2002). The short career length of the majority of jockeys indicate that they may not be physically or mentally prepared or able to meet the demands of riding in a race, thus not able to either meet the weight requirements, or perform successfully. Reducing the numbers of licensed jockeys may help to extend future jockeys' careers by ensuring there were sufficient riding opportunities. Better selection of and support for candidates who are able to join the high workload jockey cohort would reduce risk to both horse and rider and loss of athletes from the sport.

4.7 Conclusions

The majority of jockeys in New Zealand over the 2005/6 - 2018/9 racing seasons had short careers of two years, whilst jockeys who rode in more races had longer careers. The 11% of jockeys with careers of greater than 10 years rode at consistently low weights, had a lower fall incidence rate, and were more likely to win races than jockeys with shorter careers. In determining jockey career lengths, the ability to obtain rides (and to make riding weights) was more important than falling or winning. There was a high rate of loss of apprentices, the majority of them leaving one year after their first race day ride, highlighting the importance of developing appropriate selection criteria for jockeys.

4.8 References

Baker, J., Koz, D., Kungl, A.-M., Fraser-Thomas, J., & Schorer, J. (2013). Staying at the top: playing position and performance affect career length in professional sport. *High Ability Studies,* 24(1): 63-76. doi:10.1080/13598139.2012.738325

Bolwell, C. F., Rogers, C. W., & Gee, E. K. (2014). Descriptive epidemiology of race-day jockey falls and injuries in New Zealand. *Comparative Exercise Physiology,* 10(1): 49-55. doi:10.3920/cep13036

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science,* 56(1): 77- 81. doi:10.1071/an13442

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Curry, B. A., Hitchens, P. L., Otahal, P., Si, L., & Palmer, A. J. (2016). Australian insurance costs of jockeys injured in a race-day fall. *Occupational Medicine,* 66(3): 222-229. doi:10.1093/occmed/kqv150

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Sciences,* 29(8): 791-799. doi:10.1080/02640414.2011.560173

Filby, M., Jackson, C., & Turner, M. (2012). Only falls and horses: accidents and injuries in racehorse training. *Occupational Medicine,* 62(5): 343-349. doi:10.1093/occmed/kqs068

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011a). Are physiological attributes of jockeys predictors of falls? A pilot study. *BMJ Open,* 1(1): e000142. doi:10.1136/bmjopen-2011-000142

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011b). Predictors of race-day jockey falls in jumps racing in Australia. *Accident Analysis and Prevention,* 43(3): 840-847. doi:10.1016/j.aap.2010.11.003

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L., & Fell, J. (2010). Predictors of race-day jockey falls in flat racing in Australia. *Occupational and Environmental Medicine,* 67(10): 693-698. doi:10.1136/oem.2009.050567

Jeffcott, L. B., Rossdale, P. D., Freestone, J., Frank, C. J., & Towers-Clark, P. F. (1982). An assessment of wastage in Thoroughbred racing from conception to 4 years of age. *Equine Veterinary Journal,* 14(3): 185-198.

Jeon, S., Cho, K., Ok, G., Lee, S., & Park, H. (2018). Weight loss practice, nutritional status, bone health, and injury history: A profile of professional jockeys in Korea. *Journal of Exercise Nutrition and Biochemistry,* 22(3): 27-34. doi:10.20463/jenb.2018.0021

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. J. (2020). Physical preparation strategies of professional jockeys. *Jornal of Strength and Conditioning Research*. doi:10.1519/JSC.0000000000003514. Epub ahead of print.

Kiely, M. A., Warrington, G. D., 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. doi:10.23736/S0022-4707.18.08196-3

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport,* 23: 1154-1160. doi:https://doi.org/10.1016/j.jsams.2020.05.015

Leydon, M. A., & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12: 220-237.

New Zealand Thoroughbred Racing. (2019). *Handicapping guide*. Wellington, New Zealand: https://loveracing.nz/OnHorseFiles/LoveRacing/Articles/2018/2019%20Handicapping%20Policy%20(Effective%20from%201%20August%202019).pdf. Accessed: Jan 2020

O'Connor, S., Warrington, G., Mb, A. M., & Cullen, S. (2018). A 9-year epidemiologic study (2007-2015) on race-day jockey fall and injury incidence in amateur Irish horse racing. *Journal of Athletic Training,* 53(10): 950-955. doi:10.4085/1062-6050-339-17

Press, J. M., Davis, P. D., Wiesner, S. L., Heinemann, A., Semik, P., & Addison, R. G. (1995). The national jockey injury study: an analysis of injuries to professional horse-racing jockeys. *Clinical Journal of Sport Medicine,* 5(4): 236-240.

Sobczyńska, M. (2007). The effect of selected factors on length of racing career in Thoroughbred racehorses in Poland. *Animal Science Papers and Reports,* 25(3): 131-141.

Speed, H., Seedsman, T., Morris, T., and Sullivan, R. (2001). *The welfare of retired jockeys.* Melbourne: Victoria University of Technology, Centre for Rehabilitation, Exercise and Sports Science.

Tanner, J. C., Rogers, C. W., & Firth, E. C. (2013). The association of 2-year-old training milestones with career length and racing success in a sample of Thoroughbred horses in New Zealand. *Equine Veterinary Journal,* 45(1): 20-24. doi:10.1111/j.2042-3306.2011.00534.x

Trowbridge, E. A., Cotterill, J. V., & Crofts, C. E. (1995). The physical demands of riding in National Hunt races. *European Journal of Applied Physiology,* 70(1): 66-69.

Vamplew, W. (2016). Still crazy after all those years: continuity in a changing labour market for professional jockeys. *Sport in Society,* 19(3): 378-399. doi:10.1080/17430437.2015.1059015

Waller, A. E., Daniels, J. L., Weaver, N. L., & Robinson, P. (2000). Jockey injuries in the United States. *The Journal of the American Medical Association,* 283: 1326 - 1328.

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

Witnauer, W. D., Rogers, R. G., & Saint Onge, J. M. (2007). Major league baseball career length in the twentieth century. *Population Research and Policy Review,* 26(4): 371-386. doi:10.1007/s11113-007-9038-5

5 Chapter Five - Physical activities of jockeys during a working week

Published in part in the following publication.

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Physical activities of jockeys during a working week. *Comparative Exercise Physiology*, 18(1), 75-83. doi:10.3920/cep210011

5.1 Foreword to Chapter Five

The previous chapter demonstrated that jockeys with higher competitive workloads (numbers of race rides) had longer, safer, and more successful careers. The combined data from Chapters 2 - 4 indicate that the typical jockey's career was very short and heavily influenced by the ability to obtain race rides early in their career. It appeared that higher numbers of race rides not only increase the chance of success, but the higher frequency of race riding may increase "competition fitness" and reduce the risk of injury. The increased chance of falling with increasing races ridden per day indicates that fatigue (mental and physical) may play a role in race day falls and that physical training outside race riding may be of benefit. The next stage of the study was to quantify the physiological demands of jockeys during the working week, both in training and competition.

The normal training (workday) activities of a jockey in New Zealand were relatively unknown and quantified only in qualitative terms. The quantification of daily competitive and training loads is important to fully understand the broad physiological demands experienced by jockeys and what may be lacking in those jockeys with lower competitive workloads. Therefore, the next step of this research was to examine the physical activities (riding and non-riding) of jockeys during a working week.

5.2 Abstract

Horse racing and training is a physically demanding sport. The aims of this study were to quantify the physical activities of jockeys during a working week and to investigate self-reported fall and injury incidence rates of jockeys at work. A daily workload diary examining workday and physical activities was emailed to all jockeys licensed to ride in a race in New Zealand in 2020. Sixty-three jockeys (25 apprentices, 33 professional and 5 amateur riders) began the diary, representing 38% of the licensed population of jockeys in New Zealand. Jockeys worked a median of 44 (IQR 33 - 57) hours, 6-days per week. A median of 7 (IQR 6 - 9) horses were ridden per day, comprising 58% of work time, with 11 (IQR 7 - 15) hours per week spent at training pace. Elite jockeys (high performance in the premiership table) spent more time riding in races (1.1, IQR 0.7 - 1.2 hours per week) than non-elite jockeys (0.0, 0.0 - 0.4, $p = 0.01$), with 29% (IQR 0 - 54%) of their weekly rides as race rides. Extra physical training was conducted by 72% of jockeys, which consisted mainly of low intensity exercise such as pleasure riding (56%) and walking (43%). Falls during morning exercise work were recorded by 87% of respondents, 40% of which had sustained an injury in the previous 12 months. Jockeys who participated in extra physical training had higher fall incidence rates per 1,000 horses ridden in morning exercise work (3.5, 95% CI 3.1 - 3.9, $p = 0.002$) but lower fall incidence rate in race riding (2.1, 95% CI 1.5 - 2.8, $p < 0.001$) than jockeys who did no extra training (2.5, 95% CI 2.0 - 3.0 and 5.9, 95% CI 3.8 - 9.0). Elite jockeys experience a level of specific race exercise which is lacking in the other jockeys.

5.3 Introduction

Full time professional jockeys are elite athletes, and race riding requires physical strength, stamina and the ability to make decisions quickly during a physically demanding race (Cullen *et al.*, 2015; Dolan *et al.*, 2013; Trowbridge *et al.*, 1995; Wilson *et al.*, 2013). To meet the high physical demands of race riding, providing a regular physical training schedule is important to improve performance. The workload of an athlete quantifies the physiological demand during training and/or competition. A greater understanding of the magnitude of both internal (e.g. heart rate, oxygen consumption and rating of perceived exertion) and external (e.g. time, distance and accelerometer derived parameters) training loads provide greater insight into the physical demands experienced by jockeys during training and competition, and are important in the prescription of an optimal physical training load (Bourdon *et al.*, 2017; Windt *et al.*, 2017). Internal workload of jockeys during competition and daily riding has been quantified (Cullen *et al.*, 2015; Kiely *et al.*, 2020b; Kiely *et al.*, 2019; Trowbridge *et al.*, 1995) but to date, the only quantitative external workload information for jockeys has reported the number of races ridden by a jockey per race day or season, with no information on the amount, distance or duration of other daily riding work undertaken by jockeys (Cullen *et al.*, 2015; Dolan *et al.*, 2011; Legg *et al.*, 2020a; Leydon *et al.*, 2002; Trowbridge *et al.*, 1995; Warrington *et al.*, 2009).

Jockeys often work 20 - 35 hours each week in addition to competing in weekly races (Kiely *et al.*, 2020a; Leydon *et al.*, 2002). A typical working week for a jockey may vary considerably depending on their status and racing jurisdiction. However, the racehorses they ride require daily training (morning exercise work) at a canter or gallop as the primary method to condition the horse for racing. Thoroughbreds in Australasia are typically trained 5 - 6 days a week, two of which include fast work (gallop) days (Morrice-West *et al.*, 2020; Rogers *et al.*, 2007). A typical working day for a jockey in New Zealand usually involves riding morning exercise work for their local racehorse trainer, normally 5 - 6 days a week (Leydon *et al.*, 2002). Each trainer may have several jockeys (both professional and apprentice) or exercise riders (riders who are not licensed to ride in a professional race, but ride horses in training and gallop work), who ride multiple horses each morning. Each horse has a physical training programme developed by their trainer to prepare the horse for racing. Additional workday activities of a jockey usually include activities relating to the care of the horse such as mucking out, grooming horses and carrying buckets of feed and water (Kiely *et al.*, 2019; Leydon *et al.*, 2002).

Working in addition to sports training 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 (Kellmann, 2010). Working with horses is also a potential source of injury to jockeys, with 15% of Irish jockeys sustaining injuries from horse related activities outside of a race, half of which resulted in the jockey missing racing and most (60%) due to a fall during morning exercise work (O'Connor *et al.*, 2020). This was similar in British racing stables, with the majority of staff injury due to falling from a horse, with accidents 6 times more prevalent in exercise riders than jockeys (Filby *et al.*, 2012). Exercise work necessarily involves less experienced horses, which may act unpredictably during training, potentially contributing to the higher fall rates observed by exercise riders than jockeys. However, jockeys have been found to have greater physical fitness than exercise riders, which has been associated with lower risk of falling (Hitchens *et al.*, 2011). This highlights the importance that physical conditioning may have in the prevention of falls and thus injury potential both during and outside of racing.

Jockeys rarely participate in additional off-horse physical training except as a measure to reduce weight (Dolan *et al.*, 2011; Kiely *et al.*, 2020a; Leydon *et al.*, 2002). Workday activities, though horse-centric, may be viewed by the jockey as sufficient physical preparation for race riding. However, self-reported fatigue is prevalent among the jockey population and a substantial proportion of the jockey population is thought to remain in a state of chronic energy deficiency due to restricted food intake required to meet weight riding requirements (Dolan *et al.*, 2011).

Jockey daily workload and training has not been quantitatively measured and is important to understand for both the prevention of injury (due to falls or gradual onset due to repetitive loading) and in the designing of physical training programmes. There is a lack of published literature on the frequency or variation of jockey specific workloads or activities outside of racing. Therefore, the aim of this study was to describe and quantify the physical activities of jockeys during a working week. A secondary aim was to investigate the self-reported incidence of falls and injury for jockeys during their working week.

5.4 Methods

An online Qualtrics (Qualtrics, Version 11/2020, Provo, UT, USA) survey was created to record the workday routines and daily physical activity of licensed jockeys (Appendix D). The online survey consisted of 84 open, closed and multiple-choice questions in two sections. Section one encompassed anthropometric information about the participant as well as their number of years riding, falls and injuries. Section two comprised of a daily diary where participants recorded their working hours and duties, number of horses ridden (distance, times) and any extra physical activity undertaken. Participants were provided with a personalised daily summary of the estimated number of horses and hours spent riding based on their answers for that day and week. Prior approval for the survey was granted by New Zealand Thoroughbred Racing (NZTR), the regulatory body for Thoroughbred racing in New Zealand.

5.4.1 Participants

Jockeys in New Zealand can be separated into the following categories: amateur, apprentice, and professional (including jumps jockeys). Amateur jockeys ride in a limited number (15) of amateur races without payment each year. Apprentice jockeys are young (minimum 15 years of age), who are given a weight allowance of 1 - 4 kg to compensate for their inexperience in race riding (New Zealand Thoroughbred Racing, 2019a). This allowance is reduced with the number of their previous wins. Professional jockeys must be 18 years of age or over and have completed a four-year apprenticeship (New Zealand Thoroughbred Racing, 2019b). There are no specific fitness requirements or guidelines (other than riding competency) for jockeys in New Zealand.

Elite jockeys were identified as being in the top 20 jockeys (or apprentices) in the New Zealand premiership table published by NZTR which provides jockey rankings based on their performances throughout the season (1 August 2020 – 31 July 2021). Non-elite jockeys ranked lower than 20 in the premiership table.

The link to the online survey was sent via email to all 166 jockeys, apprentices and amateur riders registered with NZTR in 2020. Participants under the age of 16 were excluded from the study. The introduction of the survey explained the aims and objectives of the research and covered informed consent and use of the data. Ethical approval for the survey was granted by the Massey University Human Ethics Committee (SOA 20/27).

The survey was sent on Monday 30 November 2020, with daily reminders containing a personalised link to continue filling in the survey over the course of the week. Injured or suspended riders were advised to fill in the survey based on a typical working week. Follow up emails were sent weekly for 4 weeks to encourage full participation in the study.

5.4.2 Statistical Analysis

Data were extracted from the Qualtrics survey software as .csv files and collated in a customised database. Data were then examined for distribution and errors using simple descriptive statistics and checked for normality using the Shapiro-Wilk's test. Mean and standard deviation (SD) were used to describe normally distributed population level data. Median and interquartile range (IQR) were used to describe continuous data that were not normally distributed and counts and percentages were used to describe categorical data. Differences between the license types were tested with Kruskal-Wallis (for nonparametric data) and chi-squared tests (for associations between categorical variables), each with a significance level of $p < 0.05$.

The annual number of rides jockeys completed during morning exercise work or race riding was extrapolated from the average number of horses ridden per day for each jockey (from survey), assuming a 6-day working week with 4 non-working weeks during the year (based on New Zealand employment law). This value was used to calculate incidence rates as falls per 1,000 rides. Injury incidence was calculated as number of injuries requiring time off work per 1,000 falls. Weekly data was calculated using the sum of the median daily hours worked or ridden. To calculate the time spent in race riding, the length of time of a race was estimated as 2 minutes, based on the median race distance in New Zealand and speed of horses galloping (Bolwell *et al.*, 2016).

Exercise was divided into resistance exercise (including gym work, circuit training, farm work and yoga/pilates) and aerobic exercise (including pleasure riding, running, walking, rowing ergometry, cycling, swimming and team sports). Exercise volume metrics were calculated using the sum of daily median exercise volumes. All statistics were conducted in RStudio (version 1.2.5001, 2019, R Foundation for Statistical Computing, Vienna, Austria).

5.5 Results

5.5.1 Participants

Sixty-three licensed professional jockeys, apprentices, and amateur riders participated in the study. This represented 38% of the 166 licensed jockeys in New Zealand in 2020. Participants included 33 professional jockeys (n = 11 female, n = 22 male), 25 apprentices (n = 10 female, n = 15 male) and 5 (n = 4 female, n = 1 male) amateur riders who began the survey. Elite jockeys (n = 10) included 7 professional jockeys and 3 apprentices. The physical and career characteristics of respondents are described in Table 5.1, stratified by license type. Professional jockeys were older and had more riding experience than apprentices and amateur riders. Participant responses declined over the course of the week, with 31 (49%) of respondents completing the survey for the entire 7 days.

Table 5.1 Characteristics (median and interquartile range) of 33 professional jockeys, 25 apprentices and 5 amateur riders licensed in New Zealand during 2020.

Characteristic	**Professional**	**Apprentice**	**Amateur**	**P value**
Age (years)	32 (28 - 36)^{a}	25 (22 - 28)^{b}	29 (23 - 45)^{ab}	0.002
Height (cm)	162 (155 - 168)	160 (156 - 168)	163 (157 - 165)	0.9
Riding weight (kg)	54 (52 - 56)^{a}	51 (50 - 53)^{b}	58 (58 - 60)^{c}	<0.001
Years held current license	1 (0 - 8)	3 (2 - 4)	0 (0 - 1)	0.2
Total years horse riding	20+ (12 - 20+)^{a}	10 (8 - 15)^{b}	19 (15 - 20+)^{ab}	0.002
Years spent exercise work riding	13 (9 - 19)^{a}	7 (4 - 9)^{b}	15 (7 - 20+)^{ab}	<0.001
Years spent race riding	10 (6 - 17)^{a}	3 (1 - 4)^{b}	2 (1 - 5)^{b}	<0.001

^{ab}medians with differing superscripts differ, $p < 0.05$,

5.5.2 *Work and exercise*

The majority (89 ± 4%) of respondents began their workday between 4 am - 6 am, finishing their morning shift between 9 am - 11.30 am (70 ± 6%). Afternoon work began at 2 pm - 3pm (68 ± 6%), finishing between 4 pm - 5.30 pm (68 ± 14%). Apprentices had consistent working hours, with an average of 85 ± 8% of apprentices following this schedule from Monday - Friday. Working hours were more variable on the weekends, and shorter on Sundays (when they were worked).

Most (68%) respondents worked 6-day weeks with Sunday as a rest day, working a median of 44 (IQR 33 - 54) hours per week (Table 5.2). Amateur riders and apprentices worked more hours per week than professional jockeys. Elite jockeys spent more time riding in races than non-elite jockeys, but there was no difference between license types. Time spent engaged in physical exercise outside of work hours was similar for all jockeys, most of which (68%, IQR 60 - 86%) was lower intensity exercise such as walking or riding rather than running or gym work.

Table 5.2 Number of hours per week (median and IQR) engaged in physical activities for jockeys licensed in New Zealand during 2020, stratified by license type (professional, apprentice and amateur) and riding level.

	License				Jockeys			All Jockeys
Activity	**Professional**	**Apprentice**	**Amateur**	**P value**	**Elite**	**Non-elite**	**P value**	
Work hours	38 (29 - 52)[a]	46 (36 - 60)[b]	55 (46 - 59)[b]	0.05	33 (25 - 43)	45 (33 - 58)	0.2	44 (33 - 57)
Exercise riding	20 (7 - 27)	21 (15 - 30)	30 (22 - 36)	0.4	7 (1 - 16)	23 (14 - 30)	0.2	22 (13 - 30)
At Races	0 (0 - 7)	0 (0 - 5)	0 (0 - 5)	0.5	14 (3 - 27)	0 (0 - 1)	0.2	0 (0 - 5)
Canter/Gallop work	11 (7 - 15)	10 (6 - 14)	10 (8 - 13)	0.4	8 (6 - 11)	11 (7 - 15)	0.5	11 (7 - 15)
Race Riding	0.2 (0.1 - 1.1)	0.0 (0.0 - 0.5)	0.0 (0.0 - 0.1)	0.4	1.1 (0.7 - 1.2)	0.0 (0.0 - 0.4)	0.01	0.0 (0.0 - 0.5)
Non-work physical exercise	3 (0 - 8)	2 (0 - 8)	2 (1 - 4)	0.9	1.5 (0 - 3.9)	1.5 (0 - 7.5)	0.7	1.5 (0 - 6.5)
Resistance Exercise[1]	0.0 (0.0 - 3.0)	1.0 (0.0 - 3.5)	0.0 (0.0 - 0.0)	0.2	0.5 (0.0 – 1.0)	0.0 (0.0 - 2.5)	0.4	0.0 (0.0 – 2.0)
Aerobic Exercise[2]	1.5 (0.0 - 4.0)	1.5 (0.0 - 5.5)	1.0 (0.5 - 4.0)	1.0	0.5 (0.0 – 2.6)	1.0 (0.0 - 5.0)	0.7	1.0 (0.0 - 4.5)

[ab]medians with differing superscripts differ, $p < 0.05$, [1] Resistance exercise includes gym workouts, circuit training, farm work and yoga/pilates, [2]Aerobic exercise includes pleasure riding, running, walking, rowing ergometry, cycling, swimming and team sports.

Riding morning exercise work was the main activity of the working day comprising a mean of 58 ± 2% of the time at work from Monday to Saturday for all respondents with 94 ± 4% respondents riding horses at work each day. The median number of horses ridden daily for morning exercise was 7 (IQR 6 - 9) for all license types. Respondents spent between 5 - 15 minutes riding each horse at working pace, with the most common workout for each horse consisting of either one (32% of workouts) or two laps (61% of workouts) of the racetrack or equivalent distance (1 lap = 1,600 – 1,800m). Other activities included driving to and attending races (14 ± 6% of time), care of horses (10 ± 2% of time), mucking out (7 ± 1% of time), cleaning and maintenance work (6 ± 2% of time), and administration such as race ride nominations and apprentice school (< 1% of time). On Sunday most of work time for those who worked was spent in the care of horses.

The number of horses ridden at the races was more variable, with professional jockeys riding a median of 5 (IQR 0 - 8) horses, apprentices 2 (IQR 1 - 3) horses and amateur riders 2 (IQR 1

- 2) horses on the day with the highest number of races (Saturday) during the survey period. On this day, elite jockeys (n = 4) rode a median of 9 (IQR 8.5 - 9) horses in races and 7 (IQR 6 - 9) horses in morning exercise work, whilst non-elite jockeys (n = 29) rode a median of 1 (IQR 0 - 3) horses in races and 6 (IQR 5 - 8) horses in morning exercise work. Elite jockeys reported a median of 29% (IQR 0 - 54%) of their weekly rides as race rides, whereas non-elite jockeys reported a median 4% (IQR 0 - 20%, p = 0.3) of their weekly rides as race rides. All jockeys rode a mean of 1 ± 3 extra horses during morning exercise work on the days where they did not have a race.

Most respondents (n = 42/58, 72%) engaged in extra physical activity outside of their working hours at some point throughout the week. For these jockeys, the number of hours spent engaged in out of work physical activity is shown in Table 5.3. Monday and Friday were the most common days to conduct extra physical training. On Monday, a day with no racing, extra physical exercise was undertaken by 75% of the elite jockeys (n = 8) and 54% of the non-elite jockeys (n = 50). On the weekend, 25% of elite jockeys and 27% of non-elite jockeys engaged in out of work physical activity.

Table 5.3 Exercise volume (hours) per week (median and IQR) for jockeys who engaged in out of work physical activity, stratified by license type (professional, apprentice and amateur) and riding level.

	License				Jockeys			
Activity	**Professional**	**Apprentice**	**Amateur**	**P value**	**Elite**	**Non-elite**	**P value**	**All Jockeys**
Non-work physical exercise	6.3 (3.5 - 13.1)	6.5 (2.0 - 11)	3 (1.8 - 4.3)	0.9	3.8 (2.4 - 5.9)	6.5 (2.5 - 11.5)	0.7	6.3 (2.5 - 10.9)
Resistance Exercise[1]	3.3 (1.9 – 6.9)	3.5 (1.0 – 11.0)	1.5 (1.5 - 1.5)	0.2	1.0 (1.0 - 3.0)	3.5 (1.5 – 8.8)	0.4	3.0 (1.5 – 8.0)
Aerobic Exercise[2]	3.5 (2.8 – 8.8)	5.0 (1.5 - 11.8)	2.5 (0.9 - 4.3)	1.0	3.0 (1.5 – 3.5)	5.0 (2.0 - 10.0)	0.7	4.0 (1.9 – 8.4)

[1] Resistance exercise includes gym workouts, circuit training, farm work and yoga/pilates, [2] Aerobic exercise includes pleasure riding, running, walking, rowing ergometry, cycling, swimming and team sports.

The majority of physical exercise undertaken by jockeys was aerobic (Table 5.3). The most common physical activity was pleasure riding, undertaken by 56% of those who engaged in extra physical training. Walking was the next most common activity (43%). Other activities included running (30%), cycling (26%), yoga/pilates (26%), gym/circuit training (25%), swimming (17%) and team sports (14%). Less than 1 hour per week was spent on the majority of these activities. Farm work was undertaken daily by a minority of respondents.

5.5.3 Falls and injury

Most (87%, n = 52/60) of the respondents reported having fallen from a horse during morning exercise work during the last 12 months, of which 40% (n = 21/52) sustained an injury requiring time off work. One third (34%, n = 19/56) reported having fallen during a race in the previous 12 months, of which 37% (n=7/19) sustained an injury requiring time off work (Table 5.4). Horse behaviour was the main reason given for falling (79% of respondents), with other riders (18%), gear issues (11%) and other reasons (16%) contributing to falls. Jockeys who reported exercising during the week had a higher fall rate per 1,000 rides in morning exercise work (3.5, 95% CI 3.1 – 3.9, p = 0.002) than those jockeys who reported doing no exercise during the week (2.5, 95% CI 2.0 – 3.0). However, jockeys who exercised reported less than half the fall rate in race riding (2.1, 95% CI 1.5 – 2.8, $p < 0.001$) than jockeys who reported no out of work exercise during the week 5.9, 95% CI 3.8 – 9.0). Jockeys who exercised reported an injury rate per 1,000 falls of 120 (95% CI 88 - 163) during morning exercise work and 178 (95% CI 95 - 333) during race riding, whereas jockeys who did no exercise reported injury rates of 85 (95% CI 45 - 159, $p = 0.3$) during morning exercise work and 143 (95% CI 50 - 407, $p = 0.3$) during race riding.

Table 5.4 Self-reported falls and injury requiring time off work incidence rates (IR with 95% CI) of licensed professional jockeys, apprentices and amateur riders during morning exercise work and race riding in New Zealand during 2020.

	Professional	Apprentice	Amateur	P value[1]
Total n	30	24	5	
Morning exercise work				
Number of jockeys who fell in the last 12 months (%)	27 (90%)	20 (83%)	4 (80%)	0.7
Number of reported falls	201	154	41	
Number of jockeys who were injured in the last 12 months	11 (39%)	8 (32%)	1 (20%)	0.7
Number of injuries	17	16	2	
Mean estimated number of morning exercise rides per jockey per year (± SD)	2,303 ±103	2,091 ± 197	1,640 ±41	0.2
Fall incidence rate (95% CI)	2.9 (2.5 – 3.3)[a]	3.1 (2.6 – 3.6)[a]	5.0 (3.6 - 6.8)[b]	0.006
Injuries per 1000 falls (95% CI)	85 (54 - 133)	104 (65 - 165)	49 (13 - 188)	0.4
Race riding				
Number of jockeys who fell in the last 12 months (%)	12 (43%)	6 (26%)	-	0.3
Number of reported falls	41	15	-	
Number of jockeys who were injured in the last 12 months	5 (19%)	2 (9%)	-	0.6
Number of injuries	9	2	-	
Estimated number of race rides per jockey per year (± SD)	478 ± 67	425 ±82	-	1
Fall incidence rate (95% CI)	3.3 (2.4 – 4.4)[a]	1.5 (0.9 – 2.4)[b]	-	0.03
Injuries per 1000 falls (95% CI)	220 (123 - 391)	133 (37 - 484)	-	0.4

[1]p value calculated with chi square test; [ab]values with different superscripts are significantly different within rows, $p < 0.05$

5.6 Discussion

This was the first study to quantify the physical activities of jockeys in New Zealand during a working week. The sampling frame of this survey was limited by the voluntary participation of licensed jockeys. This may have resulted in selection bias or willingness to participate based on familiarity and use of online platforms (although given the age of the participants, this is unlikely to have been a factor). Bias instead may have been based on interest in the study and time constraints. The use of an online platform to distribute the survey enabled a larger reach of the widely dispersed jockey population in New Zealand but meant that the accuracy of self-reported answers were unable to be verified. However, individual answers were checked by an industry knowledgeable author to accept their plausibility before inclusion in the analysis.

The profile (age, gender, anthropometric distribution) of participants was similar to that of all licensed jockeys reported racing in New Zealand in the last 14 years (Legg *et al.*, 2020a), indicating the sample was representative of licensed jockeys in New Zealand. However, there was a slightly higher proportion of apprentices completing the survey (44% respondents, vs 32% of jockey population registered as apprentices), so results may be more indicative of apprentice workload. The height and weight of both professional jockeys and apprentices have increased slightly since 2002 (Leydon *et al.*, 2002). Professional jockeys and amateur riders were older and had more riding experience than apprentices, which was expected as apprentices are at the beginning of their career.

One major limitation of the survey was that it encompassed data for only one week. A jockey's work and daily routine may vary substantially from week to week, depending on the racing season, scheduled races and horses coming into work. However, apprentices in particular, are likely to have similar weekly routines and given the lack of compliance of jockeys completing the entire survey it was unfeasible to conduct the survey for longer than one week. Data collection took place at the beginning of the flat season and end of the jumps racing season. During the week investigated, there were races around the country from Wednesday to Saturday, with trials held on Tuesday and Wednesday, enabling jockeys in any region to attend races at least once if they obtained a ride during the week. Saturday had two race venues, one of which was a premier meeting. The weather during the week was typical spring weather, with some rain and wind, but mild enough not to affect outdoor exercise work.

5.6.1 Work and exercise

Professional jockeys and apprentices worked substantially more hours per week in this study than the 31 ±13 hours for apprentices and 28 ± 16 hours worked by flat jockeys in Ireland (Kiely *et al.*, 2020a). However, jockeys in this study self-reported spending 14% of their workday time at the races, resulting in a similar working week for professional jockeys (33 hours, IQR 25 - 45) in both countries, though apprentices in New Zealand worked longer hours (40, IQR 31 - 52) than Irish apprentices. Both professional jockeys and apprentices had similar workday riding loads (morning exercise work) which were consistent from Monday to Saturday.

Participants engagement in the survey decreased over the course of the week, possibly due to progressive physical and mental fatigue over the course of the week, resulting in either lack of time or interest in the study. Working hours were more variable on weekends, possibly due to the higher number of races on these days. Apprentices had more consistent working hours, likely because they are apprenticed to a trainer who sets their work, as opposed to professional jockeys who may have to organise their own rides and work schedules. Monday and Friday were the most common days for extra physical exercise by all jockeys. Monday is not a common race day, so jockeys may have extra time on these days to exercise. Most premier races in New Zealand are held on Saturdays, so it is possible that jockeys who exercise on a Friday may be doing so to help meet their riding weights for the following days racing.

Jockeys in this study spent approximately 11 hours a week riding horses at training pace (canter/slow gallop). Jockeys riding in races adopt a different posture and work at a higher intensity than when riding at training pace, which has been estimated to expend 7.1 ±1.8 $kcal \cdot min^{-1}$ of energy, with mean heart rates (HR) of 135 ±15 bpm (71 ±7% HR_{peak}) and $\dot{V}O_2$ of 27 ±5 $mL \cdot kg^{-1} \cdot min^{-1}$, comparable to leisurely cycling exercise (Kiely *et al.*, 2019). In contrast, during simulated and competitive flat racing, jockey HR's reach 172 -189 bpm (80 – 94% of maximal), with peak $\dot{V}O_2$ of 46 – 57 $mL \cdot kg^{-1} \cdot min^{-1}$ and estimated energy expenditure of 22 – 43 $kcal \cdot min^{-1}$, with jockeys exercising at maximum physiological capacity (Cullen *et al.*, 2015; O'Reilly *et al.*, 2017; Trowbridge *et al.*, 1995). Elite jockeys had more race day rides than other jockeys, riding 30% of their rides throughout the week in races, whilst maintaining a similar level of trackwork riding as their counterparts. Elite jockeys had more race day rides than non-elite jockeys, riding 30% of their rides throughout the week in races, whilst maintaining a similar level of morning exercise riding as their counterparts. Jockeys who do not approximate the exercise specificity of race riding may inadvertently be training different muscles and an incorrect posture by engaging in only morning exercise work. Additionally, these jockeys are not exposed to the particular set of neuromuscular skills (reaction and coordination), a vital part of the competition specific skill set required by jockeys to ride in a race. Though the greater experience of the elite jockeys, and their ability to be selective about their mounts likely influence the lower fall rates observed in these jockeys compared to inexperienced jockeys (Hitchens *et al.*, 2012; Legg *et al.*, 2020b), the potentially higher risk of fatigue in inexperienced jockeys may contribute in part to the risk of race day falls. The higher race day fall incidence rate observed in jockeys who self-report participating in no extra physical exercise in this study, indicates that extra physical training may be a valuable tool to increase jockey safety and performance.

One quarter of New Zealand jockeys in this study did not engage in physical exercise outside of their daily work requirements, fewer than the 85% of jockeys who did no extra physical exercise in 2002 (Leydon *et al.*, 2002). This may indicate an increasing recognition by the industry of the need for extra physical fitness in jockeys. Irish jockeys had a similar uptake of non-work related physical training, with 78% of Irish jockeys engaging in extra physical activity outside of riding work (Kiely *et al.*, 2020a). In Ireland, the high participation level may be due to the recent focus in the Irish Racing Academy and Centre of Education (RACE) and associated research programmes focussing on jockey health and fitness. However, of those New Zealand jockeys who participated in physical activity outside of work, the most common activities were pleasure riding and walking, neither of which would expose the jockey to the intensity, strength, and cardiovascular requirements of race riding (Kiely *et al.*, 2019). Apprentices spent a similar amount of time engaged in resistance activities as that spent by elite jockeys riding in a race. If these resistance exercises were tailored to target the specific physical demands experienced by a jockey whilst riding in a race, this would assist jockeys to train their race specific fitness levels, enabling them to physically perform to their best potential.

Traditionally, morning exercise work in Australasia is completed at or close to dawn. This may be due to horse feeding schedules, the alleged quality of the air at dawn or the convenience of working a horse before normal working hours, particularly for smaller trainers who may have multiple jobs. The working hours of both professional jockeys and apprentices reflect this practice and have not changed since 2002 - 2007 (Leydon *et al.*, 2002; Rogers *et al.*, 2007). Working early mornings adds to risk of fatigue for workers (Caldwell *et al.*, 2008), adding an extra stressor to a job which deals with unpredictable animals on a daily basis. Long and unfavourable working hours for those in the racing industry are not restricted to New Zealand, with exhaustive work schedules, injury risk and weight difficulties key stressors for UK jockeys (Juckes *et al.*, 2021; Landolt *et al.*, 2017; Losty *et al.*, 2019). This effect may be exacerbated by the wasting practices of jockeys and may be a factor in the high number of New Zealand jockeys reporting morning exercise work falls and injury.

5.6.2 Falls and injury

There is more known about fall and injury rates of professional jockeys during racing (Hitchens *et al.*, 2009; Legg *et al.*, 2020b; O'Connor *et al.*, 2017) than during training (morning exercise work). Although there is a large focus on jockey safety during race day, a jockey in reality spends limited hours a week actually racing. Professional jockeys and apprentices spend a large part of their time in horse related activities outside of racing such as schooling, exercise riding and yard related activities (Kiely *et al.*, 2020a), increasing their exposure risk to injury. While injuries outside of races were less frequent than race day falls with lower injury rates per fall, the large amount of time spent by jockeys engaging in morning exercise work leads to a greater exposure risk to injury. Falls and subsequent injury of the jockey has the potential to lead to a substantial negative impact on jockeys, such as time loss from racing which could result in significant negative financial and career impacts in addition to health implications.

Most New Zealand jockeys self-reported having fallen from a horse during morning exercise work in the previous 12 months, with injury incidences per 1,000 falls of 85 - 104 for professional jockeys and apprentices. This was more than observed in a similar survey of Irish jockeys, with 15% of Irish jockeys sustaining an injury outside of a race with an injury incidence per 1,000 falls of 67 (IQR 47 - 95) (O’Connor *et al.*, 2020). A typical working day for a jockey may vary considerably depending on their racing jurisdiction and training norms, and these differences may influence jockey fall or injury rates per ride. Jockeys who reported engaging in extra physical exercise during the week had higher fall incidence rates and injury rates during morning exercise work than those jockeys who engaged in no extra physical exercise. This could be due to many factors, one of which may be that they are riding younger or more difficult horses, due to their greater fitness or skill. This could put them in a more dangerous situation when they do fall, resulting in the higher injury rate they report from falling. These jockeys reported half the fall rate during race rides than those jockeys who did no extra exercise, indicating that their physical fitness may be a key component of race riding safety. As this survey was focused on the workload of jockeys rather than time off work, metrics on the reasons for falls, severity of injury and length of time off work were not investigated.

Though a large sample of jockeys completed the questionnaire, recall bias may affect the findings. To minimise the effect of this recall bias, we asked jockeys to report only falls and injuries that occurred in the previous year. However, this may have led to bias as only one year was examined and trends may differ between years. The race day fall incidence rate for jockeys in New Zealand has been previously reported as 1.2 (IQR 1.1 - 1.3) falls per 1,000 rides (Legg *et al.*, 2020b), similar to what was self-reported in this study by apprentices, but lower than that reported for professional jockeys. This may be due to the previous figure only including falls that occurred during the start and finish line of the race, whereas a jockeys' recall would include any fall occurring on race day. Additionally, the number of horses ridden was estimated based on the average number of horses reportedly ridden in this questionnaire, so may not be an accurate representation of the number of rides completed by individual jockeys. Jockeys were assumed to have 4 non-riding weeks per year, based on the employment laws in New Zealand, however it is likely that an uninjured jockey may not take their full quota of holiday each year. However, jockeys often require time off work to recover from injury, this time is accounted for by assuming each jockey had a maximum of 4 non-riding weeks. Therefore, jockey fall and injury rates are only estimated in this study. Thus, future prospective research examining falls and injuries outside of race day over a number of seasons would be beneficial to examine and improve jockey health and safety in the workplace.

5.7 Conclusions

Elite jockeys experience a level of specific race exercise which is lacking in the other jockeys. This may refine their competition specific neuromuscular skills as well as provide a higher physiological workload. Jockeys who self-report participating in physical activity outside of work duties have less than half the fall incidence rate in a race than jockeys who do not. The majority of jockeys work long hours and do not participate in sufficient extra exercise akin to race riding, so are not exposed to the higher physiological demands demanded by this activity. Additionally, jockeys are exposed to long periods of risk whilst exercising a large number of horses every morning.

Determining both the physiological stressors as well as objective measures of work performed during training and competition for jockeys in New Zealand will provide a basis for the understanding of the work a jockey does and at what levels of training are necessary in order to meet the demands of race riding at a professional level. Integrating these specific demands with those of a jockeys' professional schedule is essential in developing racing specific training programmes that assist the jockey to physically (and mentally) perform to their best potential.

5.8 References

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science,* 56(1): 77- 81. doi:10.1071/an13442

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M.C., Gabbett, T.J., Coutts, A.J., Burgess, D.J., Gregson, W. and Cable, N.T. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sport Physiology and Performance,* 12(Suppl 2): S2161-S2170. doi:10.1123/IJSPP.2017-0208

Caldwell, J. A., Caldwell, J. L., & Schmidt, R. M. (2008). Alertness management strategies for operational contexts. *Sleep Medicine Reviews,* 12(4): 257-273. doi:10.1016/j.smrv.2008.01.002

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Dolan, E., Cullen, S. J., McGoldrick, A., & Warrington, G. D. (2013). The impact of making weight on physiological and cognitive processes in elite jockeys. *International Journal of Sport Nutrition and Exercise Metabolism,* 23: 399 -408.

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Sciences,* 29(8): 791-799. doi:10.1080/02640414.2011.560173

Filby, M., Jackson, C., & Turner, M. (2012). Only falls and horses: accidents and injuries in racehorse training. *Occupational Medicine,* 62(5): 343-349. doi:10.1093/occmed/kqs068

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011). Are physiological attributes of jockeys predictors of falls? A pilot study. *BMJ Open,* 1(1): e000142. doi:10.1136/bmjopen-2011-000142

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2009). The incidence of race-day jockey falls in Australia, 2002–2006. *The Medical Journal of Australia,* 190(2): 83-86. doi:10.5694/j.1326-5377.2009.tb02284.x

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2012). The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention,* 18(6): 385-391. doi:10.1136/injuryprev-2011-040255

Juckes, E., Williams, J. M., Challinor, C., & Davies, E. (2021). Racing to a staffing solution: an investigation into the current staffing crisis within the UK horseracing industry. *Comparative Exercise Physiology,* 17(1): 73-89. doi:10.3920/cep200018

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicince and Science in Sports,* 20 (Suppl 2): 95-102. doi:10.1111/j.1600-0838.2010.01192.x

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. J. (2020a). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi:10.1519/JSC.0000000000003514. Epub ahead of print.

Kiely, M., Warrington, G. D., McGoldrick, A., Pugh, J., & Cullen, S. (2020b). Physiological demands of professional flat and jump horse racing. *Journal of Strength and Conditioning Research,* 34(8): 2173-2177.

Kiely, M. A., Warrington, G. D., 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. doi:10.23736/S0022-4707.18.08196-3

Landolt, K., Maruff, P., Horan, B., Kingsley, M., Kinsella, G., O'Halloran, P. D., . . . Wright, B. J. (2017). Chronic work stress and decreased vagal tone impairs decision making and reaction time in jockeys. *Psychoneuroendocrinology,* 84: 151-158. doi:10.1016/j.psyneuen.2017.07.238

Legg, K., Cochrane, D., Gee, E., & Rogers, C. (2020a). The external workload of Thoroughbred horse racing jockeys *Sustainability,* 12. doi:https://doi.org/10.3390/su12187572

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020b). Incidence and risk factors for race-day jockey falls over fourteen years. *Journal of Science and Medicine in Sport,* 23: 1154-1160. doi:https://doi.org/10.1016/j.jsams.2020.05.015

Leydon, M. A., & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12: 220-237.

Losty, C., Warrington, G., McGoldrick, A., Murphy, C., Burrows, E., & Cullen, S. (2019). Mental health and wellbeing of jockeys. *Journal of Human Sport & Exercise,* 14(1): 147-157.

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., & Whitton, R. C. (2020). Training practices, speed and distances undertaken by Thoroughbred racehorses in Victoria, Australia. *Equine Veterinary Journal,* 52(2): 273-280. doi:10.1111/evj.13156

New Zealand Thoroughbred Racing. (2019a). *Handicapping guide*. Wellington, New Zealand: https://loveracing.nz/OnHorseFiles/LoveRacing/Articles/2018/2019%20Handicapping%20Policy%20(Effective%20from%201%20August%202019).pdf. Accessed: Jan 2020

New Zealand Thoroughbred Racing. (2019b). *New Zealand Thoroughbred Racing Incorporated Amended Rules of Racing* https://loveracing.nz/OnHorseFiles/Downloads/RULES%20OF%20RACING%20(effective%20from%201%20April%202019).pdf. Accessed: Jan 2020

O'Connor, S., Warrington, G., McGoldrick, A., & Cullen, S. J. (2017). Epidemiology of injury due to race-day jockey falls in professional flat and jump horse racing in Ireland, 2011-2015. *Journal of Athletic Training,* 52(12): 1140-1146. doi:10.4085/1062-6050-52.12.17

O'Connor, S., Warrington, G., O'Brien, S., McDermott, E., McGoldrick, A., Pugh, J., & Cullen, S. (2020). Injuries outside of horseracing: is it time to focus on injury prevention of jockeys outside of races? *The Physician and Sportsmedicine,* 49(1): 45-50. doi:10.1080/00913847.2020.1760693

O'Reilly, J., Cheng, H. L., & Poon, E. T.-C. (2017). New insights in professional horse racing; "in-race" heart rate data, elevated fracture risk, hydration, nutritional and lifestyle analysis of elite professional jockeys. *Journal of Sports Sciences,* 35(5): 441-448. doi:10.1080/02640414.2016.1171890

Rogers, C. W., Rivero, J. L. L., van Breda, E., Lindner, A., & Sloet van Oldruitenborgh-Oosterbaan, M. M. (2007). Describing workload and scientific information on conditioning horses. *Equine and Comparative Exercise Physiology,* 4(1): 1-6. doi:10.1017/s1478061507727408

Trowbridge, E. A., Cotterill, J. V., & Crofts, C. E. (1995). The physical demands of riding in National Hunt races. *European Journal of Applied Physiology,* 70(1): 66-69.

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

Wilson, G., Sparks, S. A., Drust, B., Morton, J. P., & Close, G. L. (2013). Assessment of energy expenditure in elite jockeys during simulated race riding and a working day: implications for making weight. *Applied Physiology, Nutrition and Metabolism,* 38(4): 415-420. doi:10.1139/apnm-2012-0269

Windt, J., & Gabbett, T. J. (2017). How do training and competition workloads relate to injury? The workload-injury aetiology model. *British Journal of Sports Medicine,* 51(5): 428-435. doi:10.1136/bjsports-2016-096040

6 Chapter Six - Physiological demands and muscle activity of "track-work" riding in apprentice jockeys.

Submitted in part in the following publication.

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of "track-work" riding in apprentice jockeys. *International Journal of Sports Physiology and Performance*, 17(12):1698-1705. doi:https://doi.org/10.1123/ijspp.2022-0160

6.1 Foreword to Chapter Six

The previous chapter demonstrated that the majority of jockeys spent most of their work time riding track-work, with a small proportion of weekly time at the races. Extra (non-riding) physical training for most jockeys consisted of low intensity exercise, but this too, was associated with a lower risk of falling from a horse on race-day. Elite jockeys experienced a level of specific race exercise which was lacking in the other jockeys. The studies in Chapters 3 - 5 highlighted the need for data describing the ride level specific physiological demands and performance characteristics of jockeys in both training and race rides. Therefore, the next step of this research was to quantify the physiological demands and profile the muscle activity of jockeys riding track-work.

6.2 Abstract

To enhance performance in race riding, knowledge of current training workload is required. The objectives of this study were to quantify the physiological demands and profile the muscle activity of jockeys riding track-work. Ten apprentice jockeys and 48 horses were instrumented with heart rate (HR) monitors, accelerometers and a surface electromyography BodySuit (recording eight muscle groups: *quadriceps, hamstrings, gluteal, lower back, obliques, abdominal, trapezial* and *pectoral*) which recorded continuously whilst riding their normal morning track-work. Data were extracted and time matched into 200 m sectionals for analysis once the jockey reached steady state canter (6.9 $m \cdot s^{-1}$). Jockeys rode an average (± SD) of 6 ± 1 horses each morning over 2.5 hours, spending ~30 minutes at a canter (8.8 ± 0.7 $m \cdot s^{-1}$), with mean HR of 129 ± 11 bpm and RPEs representing easy/moderate intensity exercise. Mean magnitude of horse (0.17 ± 0.01 m) and jockey COM (0.16 ± 0.02 m) displacement per stride differed from that of the jockeys' head (0.11 ± 0.01 m, $p < 0.05$). The majority of horse oscillation was damped in the upper body with a threefold reduction in the medial/lateral and fore/aft planes ($p < 0.05$), to minimise jockey head movement. Lower body muscles absorbed horse motion, with core and upper body muscles important for postural stabilisation. The physiological demands of riding track-work were low, with no evidence of fatigue. Future research of jockeys in races as comparison would identify the specific requirements a jockey specific physical conditioning programme.

6.3 Introduction

Horse racing is a physically demanding sport. Jockey and horse work together, with the jockey positioned over the horses' withers, in a crouched forward stance ('crouching') involving a continuous state of quasi-isometric movement (Kiely *et al.*, 2020b; Pfau *et al.*, 2009). Jockeys execute a limited range of movement, whilst supporting their body weight with only a small portion of the base of their foot in contact with the stirrup.

The jockey's position isolates their centre of mass (COM) from that of the horse through work done in the jockeys' legs (Pfau *et al.*, 2009). Jockeys maintain their COM as close as possible to the horses' midline, accounting for the horses' movement with asymmetrical stirrup forces, fore/aft displacement, and vertical movement simultaneously (Walker *et al.*, 2016). This requires continuous muscle activity alterations in the rider to adapt to the characteristics of the horses' different gaits. More experienced riders appear to have greater muscular control and hence appear more stable in their mounted positions than novices (Terada, 2000). This is similar in other sports (such as sailing, windsurfing and motocross), where stability of the athlete is reliant on 'quasi-isometric' muscle activity (Douglas, 2017; Spurway, 2007). Unsurprisingly, this evokes high aerobic and anaerobic demands, and jockeys exercise close to their maximal physiological capacity during a race (Cullen *et al.*, 2015; Trowbridge *et al.*, 1995).

Apprentice jockeys spend less time race riding than elite jockeys, and much of their race preparation involves riding morning exercise work or "track-work" for their racehorse trainer, normally on 5 - 6 days per week (Kiely *et al.*, 2019; Legg *et al.*, 2021). Therefore, it is important for the prescription of future physical training programmes or riding regulations, to characterise this riding load. Conversely, elite riders may spend less time riding track-work. In New Zealand, track-work generally consists of a walk to the track, followed by slow 'pacework' (canter) over ~3,000 - 4,000 m, at approximately 5 - 8 $m \cdot s^{-1}$, sometimes culminating in three-quarter pace (12 - 14 $m \cdot s^{-1}$) for the final round of the track (Legg *et al.*, 2021; Rogers *et al.*, 2004). In the lead up to racing, a horse may be galloped (>14 $m \cdot s^{-1}$) once or twice a week over a distance specific to that horses' race-day event (Morrice-West *et al.*, 2020a; Parkin, 2007; Rogers *et al.*, 2004). During track-work, the jockey has longer stirrups (thus a more open knee angle) and additional support through the reins and contact of the hands on the horse's neck, aiding the isolation of the jockey's legs against the cyclical movement of the horse. Whilst the workday activities of apprentice jockeys may be viewed by themselves (and by their trainers) as sufficient physical preparation for race riding, it has been suggested that slower track-work riding is associated with low physiological demand (Kiely *et al.*, 2019), insufficient to meet the high, near maximal, physiological demands of race riding (Cullen *et al.*, 2015; Trowbridge *et al.*, 1995). New regulations for a track-work licence in New Zealand have been based on the assumption that track-work riders require the same level of conditioning as jockeys, but there are few metrics on the physiological parameters required by riding track-work in comparison to race-day riding.

Quantification of current and expected exercise intensity or workload is the first step in building a specific training schedule to enhance performance in race riding. A greater understanding of the magnitude of both internal (both physiological and psychological stress) and external (objective measures of work done) training loads experienced by jockeys are important in the prescription of an optimal physical training load for competition specific fitness (Bourdon *et al.*, 2017). The muscles required to hold and maintain the jockey 'crouching' position on a cantering or galloping horse have not been investigated. A profile of jockey muscle activity would give further insight to enhancing the jockeys physical conditioning and optimising their on-horse stability, as well as highlighting areas in which a jockey specific off-horse exercise programme could target. Therefore, the objectives of the study were to quantify the physiological demands and to profile the muscle activity of jockeys riding track-work.

6.4 Methods

6.4.1 Participants

Ten apprentice jockeys (five male and five female), apprenticed to seven different trainers, were recruited through the New Zealand Thoroughbred Racing (NZTR) apprentice training programme. Jockeys held a current apprentice licence for 0.5 - 4 years and all had ridden in at least one race day ride. Written informed consent was obtained prior to commencement of data collection and only jockeys over the age of 16 years were considered for the study. Ethical approval for this study was provided by the Institutional Human and Animal Ethics Committees.

6.4.2 Data collection

Anthropometric data and predicted maximal aerobic capacity of the jockeys were assessed prior to (within 1 month) commencement of field data collection. Stature was assessed to the nearest cm using a portable stadiometer (Seca 213, Hamburg, Germany). Body mass was measured in light clothing (shorts and shirt) using portable digital weighing scales (Tanita InnerScan, Body Composition Monitor, BC-532). Body Mass Index (BMI) was calculated as the ratio of the weight to the square of height in metres ($kg \cdot m^{-2}$). Participants performed the multistage 20 m shuttle test (beep test) (Leger *et al.*, 1988) to determine their predicted maximal oxygen uptake ($\dot{V}O_{2\ max}$).

Field data were collected during each jockeys' normal morning track-work with their current trainer. All horses were in active race training and exercised in a race exercise saddle with jockeys responsible for their own stirrup length. All devices were synchronised to universal time and recorded continuously from the jockeys' first ride to the completion of the last ride. Data from each device were downloaded after the completion of the mornings track-work.

Speed, distance travelled, and HRs of horse and jockey were determined using Polar human and equine HR monitors attached via Bluetooth to their respective watches (Polar V800 sports watch) each containing a GPS unit at a sampling rate of 1 Hz. Linear accelerations and displacements of horse and jockey were determined via synchronised wireless, tri-axial accelerometers with a reported accuracy 0.0012 $m \cdot s^2 \sqrt{Hz}^{-1}$ (Emerald, APDM, OR, USA) and sampling rate 128 Hz, one attached to the horses girth and one to the back of the jockey's helmet. Two additional accelerometers were attached to the jockey, one at the front of the jockey's pelvis, close to their centre of mass (COM) and one centrally between the shoulder blades (upper body). These had a sampling rate of 25 Hz (*Myontec*, Finland).

Skin surface electromyography (EMG) was recorded via a specialised set of tightly fitting elasticised textile clothing (a BodySuit) (*Myontec*, Finland) worn under the jockeys' normal clothes. The BodySuit contained embedded electromyographic (EMG) electrodes that measured skin surface EMG of eight muscle groups (*pectoral*, *trapezial*, *abdominal*, *abdominal external obliques*, *quadriceps*, *hamstrings*, *gluteal* and *erector spinae/lower back*) at a sampling rate of 1,000 Hz, rectified and normalised within the software programme (*Mytontec Muscle Monitor Version 3.1.1.3)* to 25 Hz. The EMG electrodes were dampened with water before the jockey donned the BodySuit to ensure adequate signal conduction.

The time at which the jockey mounted, began and pulled up from canter and dismounted for each ride was manually recorded. After each ride, jockeys were asked to score the difficulty of the ride using Borg's rating of perceived exertion 10-point scale (RPE) (Borg, 1982), where

1 represented 'nothing at all' and 10 represented 'maximal effort'. A description of the horses' temperament/ease of riding was estimated by the jockey after each ride by assigning them a number on a "horse pull" scale from 1 - 10 (Appendix E), where 1 represented a horse that required strong urging forwards, 3 represented a horse that is 'on the bridle' (easiest to ride) and 10 a horse that they are unable to stop.

6.4.3 Statistical analysis

GPS data were used to determine the time spent riding at different gaits, with pacework (canter) defined as 6.9 $m{\cdot}s^{-1}$ and gallop defined as 13.9 $m{\cdot}s^{-1}$ in accordance with the Havemeyer consensus (Parkin, 2007; Rogers *et al.*, 2004). Data were presented as means ± SD unless otherwise stated. Normality of data distribution was tested using the Shapiro Wilk's test. Differences between groups were determined using Wilcoxon rank sum tests for non-parametric data. One-and two- way repeated measures ANOVA comparisons were used to determine differences between displacements. Cohen's effect size was calculated to determine differences between groups by calculating the difference between the means divided by the pooled standard deviation. The scale suggested by Hopkins *et al.* (2009) classes an effect size of 0.2 as a small effect, 0.6 as a moderate effect, 1.2 as a large effect and 2.0 as a very large effect.

Training impulse (TRIMP) is an integrative measure of exercise intensity based on both internal (HR) and external load (duration). TRIMP values were estimated using the Edwards method (Edwards, 1993), approximating HR_{max} as 220 – jockey age.

Three 200 m sectionals were extracted from each ride once steady state canter was achieved; "start" after the first 10 seconds of canter, "middle" derived from the midpoint of the start and end times and "end" 10s before dropping below the 6.9 $m \cdot s^{-1}$ threshold. These sectionals were used to summarise accelerometer and EMG data.

The magnitude of acceleration vector was calculated as the sum of squares of the three movement planes. Accelerometer data were filtered with a Butterworth low pass filter between 0.1 - 1.1 Hz to remove acceleration peaks. The dominant frequency (the highest magnitude sinusoidal component of the acceleration signal, corresponding to the horses' stride frequency for the horse) of the cyclical movement of horse and jockey was determined by Fast Fourier Transform. Acceleration data were integrated twice to quantify displacement following published methods (Pfau *et al.*, 2005). The time delay that separated the jockey from the horse at their respective lower point of vertical acceleration was measured for each stride by subtracting the horse minima from the closest jockey minima and averaging this within the 200 m sectional.

EMG signal power and dominant frequency were determined by Fast Fourier Transform. Linear regression was used to determine change in median frequency values for each ride (using start, middle and end sectionals). Muscle activity was calculated by taking the signal recorded for each individual muscle as a percentage of the total signal recorded from all muscles investigated over the 200 m sectional. The left/right side balance was calculated as the percentage of left side muscle signal of the total signal for each muscle group (excluding *Abdominals* which was recorded across the centre of the muscle group).

All statistical analyses were conducted using RStudio (version 3.5.1, 2018; R Foundation for Statistical Computing, Vienna, Austria) with the level of significance set at $p < 0.05$.

6.5 Results

Descriptive and mean anthropometric data for the jockeys are presented in Table 6.1.

Table 6.1 Descriptive data (mean ± SD) for apprentice jockeys (n = 10)

Variable	Mean ± SD
Age (yrs)	22 ± 3
Height (cm)	162 ± 4
Body Mass (kg)	51.8 ± 3.6
BMI ($kg·m^{-2}$)	20.0 ± 1.0
Predicted $\dot{V}O_{2\ max}$ ($mL·kg^{-1}·min^{-1}$)	44.9 ± 6.0

Horses ridden included both male and female Thoroughbred horses in active race training, ranging from 2 - 10 years old. Fifty-three separate rides were recorded with 53 different horses. Of these, 3/53 rides were gallops, 1/53 rides was young horse education and 1/53 rides was schooling. These rides were excluded from further analysis, leaving 48 pacework rides total. Each workout was divided into thirds, with warm-up, pacework and cool-down comprising equal amounts of time for each horse. The time spent in track-work by the jockeys and the corresponding internal load is shown in Table 6.2. The average HR response of jockeys whilst riding a horse at pace was ~65% of their estimated HR_{max}. Jockey average HR for the duration of the entire morning track-work session was ~50% HR_{max} (maximal HR estimated from jockeys age).

Table 6.2 Time allocation and internal load during a typical morning riding track-work for n = 10 apprentice jockeys (mean ± SD).

Activity	**Total Time (minutes)**	**HR average (bpm)**
Entire morning track-work	148 ± 36	101 ± 9
Non-riding	52 ± 16	94 ± 10
Riding	96 ± 25	107 ± 20
Riding at pace (6.9 - 13.9 $m \cdot s^{-1}$)	29 ± 9	129 ± 11
Riding at gallop	1.6 ± 0.4	160 ± 5

There was little variation in pacework workouts between jockeys, trainers and horses (Table 6.3). The jockeys rode a mean (± SD) of 6 ± 1 horses during their mornings' track-work, spending an average of 18.4 ± 5.3 minutes riding each horse (time measured from mounting to dismounting), with a mean of 10.7 ± 5.9 minutes between each ride. The average TRIMP score for jockeys riding an entire morning's track-work was 122 ± 67. The average RPE reported for pacework was 2.8 ± 1.4 (corresponding to easy/moderate intensity) and Horse Pull was 4.1 ± 1.6 (corresponding to marginal pulling). There was a linear relationship between RPE and Horse Pull, with RPE increasing by 0.5 as the level of horse pull increased (R^2 = 0.5).

Table 6.3 Descriptive data (mean ± SD) of the characteristics of track-work and internal load per ride (n = 48).

Descriptive (horse) variables	**Start**	**Middle**	**End**	**Effect size***	**Entire Ride**
Time at canter (s)	25 ± 2 [a]	23 ± 2 [b]	22 ± 2 [c]	2.4	335 ± 73
Velocity ($m \cdot s^{-1}$)	8.0 ± 0.6 [a]	8.8 ± 0.9 [b]	9.4 ± 1.1 [c]	2.4	8.8 ± 0.7
Distance (m)	200 ± 2	200 ± 3	200 ± 2	0.0	2914 ± 624
Stride count	49 ± 4 [a]	45 ± 4 [b]	43 ± 4 [c]	2.1	-
Stride length (m)	4.1 ± 0.3 [a]	4.4 ± 0.4 [b]	4.7 ± 0.5 [c]	2.1	-
Stride duration (s)	0.51 ± 0.03 [a]	0.51 ± 0.02 [b]	0.50 ± 0.02 [c]	0.8	-
HR variables					
Jockey HR average (bpm)	123 ± 15 [a]	130 ± 17 [b]	133 ± 18 [b]	0.9	130 ± 15
Jockey HR peak (bpm)	127 ± 15 [a]	133 ± 17 [b]	136 ± 17 [b]	0.8	142 ± 16
TRIMP score	0.8 ± 0.4	0.8 ± 0.4	0.8 ± 0.4	0.2	12 ± 6
Horse HR average (bpm)	136 ± 40 [a]	149 ± 33 [ab]	162 ± 38 [b]	0.9	148 ± 32

[abc] Means with differing superscripts differ ($p < 0.05$) across rows. * Effect sizes are between the first and last 200 m sectionals.

6.5.1 Accelerations and muscle activity

The dominant frequency (stride frequency) of the horse movement in all planes was consistent and jockeys experienced lower accelerations and displacements than the horse (

Table 6.4). Jockey vertical displacement was lower than and behind that of the horse in the vertical plane. In the medial/lateral and fore/aft planes, jockey dominant frequency and time difference between movements were more variable, with displacements one third that of the horse (Figure 6.1).

Table 6.4 Mean (± SD) linear accelerations and displacements of horse (n = 48) and jockey's head (n = 10) during morning track-work.

Variable		Vertical	Medial/Lateral	Fore/Aft	Magnitude
Dominant frequency (Hz)	Horse	1.97 ± 0.10	1.97 ± 0.10[*]	1.97 ± 0.10[*]	1.97 ± 0.10
	Jockey	1.97 ± 0.09 [a]	1.54 ± 0.75[b]	1.81 ± 0.53[c]	1.97 ± 0.09
	Effect size	0.1	1.2	0.6	0.0
Displacement (m)	Horse	0.16 ± 0.01 [*a]	0.09 ± 0.01 [*b]	0.10 ± 0.01 [*c]	0.17 ± 0.01[*]
	Jockey	0.12 ± 0.01 [a]	0.03 ± 0.01 [b]	0.04 ± 0.01 [c]	0.11 ± 0.01
	Effect size	5.5	13.8	10.4	6.3
Mean linear Acceleration ($m \cdot s^{-2}$)	Horse	37.7 ± 7.1[*a]	24.3 ± 7.8[*b]	34.3 ± 10.9[*a]	35.7 ± 9.6[*]
	Jockey	26.5 ± 4.1[a]	6.2 ± 2.0[b]	7.9 ± 2.1[c]	23.7 ± 3.7
	Effect size	2.7	4.5	4.8	2.3
Peak linear Acceleration ($m \cdot s^{-2}$)	Horse	52.2 ± 12.1[*a]	41.3 ± 11.4[*b]	58.6 ± 16.3[*c]	57.6 ± 12.6[*]
	Jockey	35.8 ± 8.2[a]	11.4 ± 4.3[b]	12.9 ± 4.3[c]	32.1 ± 8.3
	Effect size	2.2	4.9	5.4	3.4
Mean time difference[+] (s)		0.06 ± 0.03 [a]	-0.02 ± 0.14 [b]	-0.01 ± 0.13 [b]	0.01 ± 0.08

[+]Difference in time between jockey and horse minimum displacement. A positive time difference was obtained when the jockey's movement followed the horse and a negative value when the jockey preceded horse movement. Means with differing superscripts differ ($p < 0.05$) between horse and jockey ([*]) and across rows ([abc]).

The relative displacements of the jockey compared to horse movement is shown in Figure 6.1.

The mean magnitude of displacement for all rides of the jockey's COM was 0.16 ± 0.02 m and upper body was 0.12 ± 0.01 m. Jockey COM displacement did not differ significantly from horse displacement ($p = 0.5$), all other displacements differed significantly from each other ($p < 0.001$) with Cohen's effect size increasing from moderate 0.6 (horse – jockey COM), to very large 5 (jockey COM – upper body) and large 1.2 (jockey upper body – head). This trend was consistent both within and between rides (Table 6.5). The magnitude of displacement of the jockey's COM, upper body and head all decreased within a ride though the difference in movement between horse and jockey head increased only between the first and middle sections of the ride.

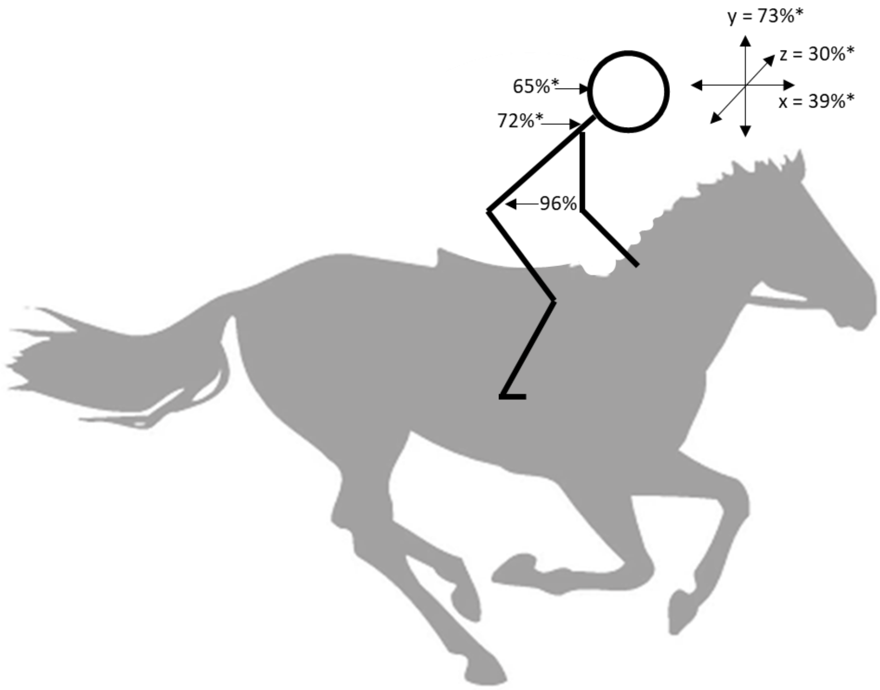

Figure 6.1 Mean magnitude of displacements relative to the horse of jockey riding track-work, and in the vertical (y), fore/aft (x) and medial/lateral (z) planes. * Denotes significant differences between jockey and horse displacement ($p < 0.05$).

Table 6.5 Mean (± SD) magnitude of displacements (m) of horse and jockey for within a ride (n = 48) and between the first and last ride (n = 10) during morning track-work. Effect sizes are between the horse and jockeys' head or first and last section.

	Within ride				Between rides		
	Start	**Middle**	**End**	**Effect Size**	**First ride**	**Last ride**	**Effect Size**
Horse	0.170 ± 0.030[1]	0.171 ± 0.030[1]	0.164 ± 0.026[1]	0.3	0.175 ± 0.032[1a]	0.161 ± 0.025[1b]	0.9
Jockey COM	0.167 ± 0.034[1a]	0.162 ± 0.038[1ab]	0.156 ± 0.036[1b]	0.4	0.165 ± 0.039[1]	0.162 ± 0.039[1]	0.2
Jockey upper body	0.132 ± 0.040[2a]	0.119 ± 0.046[2b]	0.110 ± 0.031[2b]	0.9	0.114 ± 0.035[2]	0.120 ± 0.041[2]	0.3
Jockey head	0.118 ± 0.028[3a]	0.107 ± 0.02[3b]	0.104 ± 0.032[3b]	0.7	0.111 ± 0.033[3]	0.109 ± 0.032[3]	0.1
Δ (horse - head)	0.051 ± 0.032[a]	0.062 ± 0.031[b]	0.058 ± 0.026[ab]	0.3	0.061 ± 0.029	0.052 ± 0.029	0.6
Effect size	2.5	3.1	2.9		2.8	2.6	

Means with differing superscripts differ ($p < 0.05$) across columns ([123]) and rows ([abc]).

Of the eight muscle groups investigated, the jockeys' lower body *(quadriceps, hamstrings and gluteal)* were responsible for half (49%) the muscle activity, with the upper arm *(trapezius and pectorals)* muscles and 'core' musculature *(lower back, obliques and abdominals)* each contributing one quarter (23% and 28% respectively) (Table 6.6). When interpreting these results, the relative size of muscle groups needs to be considered. The balance of muscle activity between the left and right sides of muscle groups was relatively even. The lower body muscles *(quadriceps, hamstrings, gluteal)* and the jockeys' *lower back* were activated at a similar dominant frequency as the horse movement, whereas the upper body muscles had more variable dominant frequencies. There was little change in median frequency of any muscle group within a ride (Table 6.6), although the percentage of muscle activity of the *quadriceps* decreased within a ride with a corresponding increase in activity of the core muscles *(obliques and abdominals)* (Table 6.7). Over the mornings' track-work the percentage of muscle activity by the *quadriceps* decreased and more muscle activity was apportioned to the *abdominal* muscles.

Table 6.6 Mean (± SD) surface EMG parameters of eight muscle groups for jockeys (n = 10) riding track-work (n = 48).

Muscle Group	Muscle activity (%)	Left/Right side balance (% Left side)	Dominant frequency	Slope of median frequency (per ride)
Quadriceps	29 ± 12^{a}	48 ± 6^{a}	1.9 ± 0.4^{a}	0.07 ± 0.31
Hamstrings	14 ± 5^{b}	52 ± 8^{bc}	1.9 ± 0.2^{a}	0.01 ± 0.35
Gluteal	7 ± 4^{c}	52 ± 9^{bc}	1.9 ± 0.3^{a}	-0.03 ± 0.40
Lower back	13 ± 10^{d}	54 ± 11^{c}	1.9 ± 0.3^{a}	0.07 ± 0.35
Obliques	10 ± 5^{e}	48 ± 11^{ab}	1.5 ± 0.8^{b}	0.12 ± 0.33
Abdominals	6 ± 4^{f}	-	1.5 ± 0.8^{b}	-0.02 ± 0.39
Trapezius	12 ± 9^{e}	53 ± 12^{bc}	1.4 ± 0.8^{b}	0.08 ± 0.39
Pectoralis	11 ± 7^{e}	53 ± 10^{c}	1.5 ± 0.8^{b}	-0.07 ± 0.34
Total	102*	51 ± 10	2.0 ± 0.1	

^{abc} Values with different superscripts differ significantly within columns, $p < 0.05$, *Total is greater than 100 due to rounding errors.

Table 6.7 Mean (± SD) muscle activity (%) of jockeys within a ride (n = 48) and between the first and last ride (n = 10) during morning track-work. Effect sizes are between the first and last sectional of the ride.

Muscle Group	Start	Middle	End	P value*	Effect Size	First Ride	Last Ride	P value	Effect Size
Quadriceps	32 ± 13^{1a}	28 ± 11^{1ab}	25 ± 11^{1b}	0.04	0.8	35 ± 13^{1}	26 ± 9^{1}	0.02	1.2
Hamstrings	14 ± 4^{2}	14 ± 5^{2}	14 ± 4^{2}	0.8	0.3	13 ± 4^{2}	15 ± 4^{2}	0.2	0.7
Gluteal	7 ± 3^{3}	7 ± 3^{3}	7 ± 4^{3}	0.7	0.0	7 ± 3^{3}	7 ± 3^{3}	0.7	0.1
Lower back	11 ± 3^{4}	13 ± 11^{24}	12 ± 10^{4}	0.8	0.2	11 ± 4^{24}	15 ± 18^{4}	1.0	0.5
Obliques	8 ± 4^{35}	9 ± 4^{5}	11 ± 5^{24}	0.06	0.7	9 ± 4^{34}	9 ± 4^{34}	1.0	0.3
Abdominals	5 ± 3^{6}	6 ± 4^{3}	7 ± 5^{3}	0.1	0.6	4 ± 2^{5}	8 ± 6^{34}	0.01	1.3
Trapezius	12 ± 8^{45}	12 ± 9^{45}	13 ± 11^{24}	0.8	0.2	12 ± 11^{23}	11 ± 5^{4}	1.0	0.3
Pectoralis	11 ± 7^{34}	11 ± 7^{45}	11 ± 7^{4}	0.9	0.1	10 ± 5^{23}	10 ± 6^{34}	1.0	0.1

*P value from Kruskal-Wallis test between first, middle and last 200 m sectional groups. Values with different superscripts differ significantly within columns (^{123}) and rows (^{ab}), $p < 0.05$ (Wilcoxon test).

6.6 Discussion

Jockeys rode approximately 6 horses each morning over ~2.5 hours. This was consistent with self-reported information from a New Zealand wide survey of 63 jockeys describing their physical activities over a working week (Legg *et al.*, 2021). Similar training practices have also been documented in Australia, with horses conducting slow workouts (trot or canter) or pacework (11 - 13 $m \cdot s^{-1}$), 6 days a week (Morrice-West *et al.*, 2020a). Fast workouts (> 14 $m \cdot s^{-1}$) for specific horses in their lead-up to racing may be conducted once or twice a week (Morrice-West *et al.*, 2020a; Parkin, 2007; Rogers *et al.*, 2004), but slow pacework formed the majority of a jockeys' riding load.

Jockey HR at canter (129 ± 11 bpm) was comparable to that previously reported for in Irish trainee jockeys (135 ± 15 bpm) (Kiely *et al.*, 2019). The average HR response of jockeys during the entire morning track-work session (~2.5 hours) was ~50% HR_{max}, and ~65% HR_{max} during pacework, representing moderate intensity activity. This was supported by the low RPE scores reported by the jockeys for each ride. Jockeys reported a higher RPE for horses which were less compliant (pulled more), indicating jockey effort is partially dependant on the nature of the horse (Visser *et al.*, 2008).

Jockeys' heads moved three times less than the horse in the medial/lateral and fore/aft planes, consistent with findings in previous studies (Horan *et al.*, 2021; Pfau *et al.*, 2009; Walker *et al.*, 2016). This effectively maintained their head stability in the frontal plane, which is essential for effective dynamic postural control during complex equilibrium tasks (Mester *et al.*, 1999; Pozzo *et al.*, 1995). Minimising head movement and maintaining consistency of motion may also result in long term health benefits to the jockey due to fewer acceleration and deceleration events of the head (Vibert *et al.*, 2007). Although some of the accelerations captured may include artifacts from helmet movement on the head, all helmets were pre-checked for a snug fit and securely tightened, minimising this effect.

Muscles throughout the jockeys' body worked to damp the horses' oscillations, evidenced by the magnitude of displacement of the jockey being greatest at their COM, and decreasing towards the upper body and head. A similar effect has been observed in cross-country mountain bikers who limit the transference of external vibration/movement of the bike via muscular work to maintain a steady head position with greater damping resulting in a greater work demand by the cyclist (Macdermid *et al.*, 2015). Lower body muscles (*quadriceps, hamstrings* and *gluteal)* were activated in synchrony with the horses' movements, with a dominant frequency corresponding to that of the vertical movement of the horse (i.e., stride frequency). This indicates that the activity of these muscles was reacting to and damping the major oscillation of horse movement. The time difference between horse and jockey vertical oscillation was 0.06 s, falling within the time taken for the contraction- and relaxation- time of a single muscle twitch of 0.01 – 0.1 seconds (Mester *et al.*, 1999). 'Core' muscles (*obliques* and *abdominals*) and upper body muscles (*trapezius* and *pectorals*) had a lower dominant frequency than that of the horse and higher variation in movement, indicating that they were used mainly for postural stability, stabilising the jockeys' body and head against the instability of the horse in the medial/lateral and fore/aft planes. Therefore, jockeys have control over the extent of damping by synchronous muscular activity, and the jockeys who are most successful at minimising their head movement likely have greater optimisation and hence better performance for both them and the horse. As such, measurement of jockey head movement may be a valuable assessment criteria of jockey performance and workplace health and safety.

Both within a ride and over the whole morning workout, the jockey reduced the strain on their *quadriceps* by greater 'core' activation. This was similar to the effect observed in conventional riders progressing from light seat canter, through fast canter and jumping where the dominance of their *quadriceps* was reduced with concurrent *abdominal* activation as increasing forces were transmitted through the riders' body (Douglas, 2017). This may have been a reaction to the increase in velocity of the horse towards the end of the workout, or a compensation of the muscles to prevent the onset of fatigue, using postural changes which recruit different muscles, prolonging the ability to maintain a position (Enoka *et al.*, 2008). In conventional riding, more advanced riders have better 'core' strength and muscle tone than novice riders (Douglas, 2017; Gonzalez *et al.*, 2020), highlighting that these muscles are key to stabilisation of the jockey. Therefore, this study confirms that the main muscles requiring strengthening and targeted training in jockeys are the *quadriceps*, *abdominals*, and their supporting musculature. However, there was no specific evidence of neuromuscular or central fatigue in jockeys over the morning's work.

Stabilisation of jockey movement also relies heavily on the lower leg (calf) muscles, and cervical spine and upper back muscles, with the upper body engaged in the control of the horse (de Cocq *et al.*, 2013; Poon *et al.*, 2018; Roberts *et al.*, 2010; Trowbridge *et al.*, 1995; Warrington *et al.*, 2009). These areas were unable to be investigated in the current study due to limitations of the EMG integrated clothing design. The eight muscle groups investigated were chosen to represent the major pro- and antagonist muscles in the lower body, 'core' and upper body of the jockey as a starting point to characterise the postural movement of a jockey on-horse. Additionally, the low value obtained for gluteal EMG may have been affected by underwear worn by the jockeys, meaning that the electrodes may not have picked up EMG signals from the gluteal group. However, as all jockeys were given the same instructions on donning the clothing, the problem was consistent between all jockeys.

The forces a jockey is exposed to during a race are different than riding track-work. The velocity of horses at pace work was approximately half that of race velocity of horses on turf in Australia, with stride lengths ~60% and duration 120% that of racing pace (Morrice-West *et al.*, 2020b). Peak linear head accelerations of jockeys riding track-work were half the values reported for jockeys riding in a race (Quintana *et al.*, 2019). Additionally, jockeys riding track-work adopt a different posture than riding in a race, with a wider knee angle and contact of the hands on the horse’s neck aiding the isolation of the jockey’s legs against the cyclical movement of the horse. Jockeys who do not approximate the exercise specificity of race riding may inadvertently be training different muscles and an incorrect posture by engaging in only track-work. Additionally, these jockeys are not exposed to the particular set of neuromuscular skills (reaction and coordination), a vital part of the competition specific skill set required by jockeys to ride in a race. Although jockeys do ride training gallop work and in trials and races once or twice a week, which may approximate a similar physiological exertion to that which they experience during a race, the acquisition of rides is largely dependent on jockey skill. The most successful professional jockeys in New Zealand report 30% of their weekly rides as race-rides, compared to 4% for the majority of jockeys, whilst maintaining a similar levels of morning track-work riding (Legg *et al.*, 2021). These metrics may be instrumental in determining a threshold level of race-specific exercise required by jockeys to meet the demands of race-day riding.

6.6.1 Practical Applications

Jockeys rarely participate in additional off-horse physical training regimes except as a measure to reduce weight (Dolan *et al.*, 2011). However, using races themselves to acquire physical conditioning implies that those jockeys are inadequately conditioned for racing, which is inherently dangerous. Therefore, an additional off-horse specific physical conditioning programme would be beneficial, especially for those jockeys who have few race-day rides or are inexperienced in race riding. Further investigation into the physiology of jockeys riding races would help elucidate the differences between training and competition loads and highlight areas to target in an off-horse jockey specific physical conditioning programme.

6.7 Conclusions

This study demonstrated that jockeys riding track-work exercised at a lower intensity than jockeys riding in a race. Track-work consists of slow canter work (8 - 9 $m \cdot s^{-1}$) for a daily average of 30 minutes, representing moderate intensity exercise for the jockey with HR's ~65 HR_{max}. Movement of the jockeys' head was minimised through muscular work, providing a possible measure of jockey experience or physical condition. The jockeys lower body muscles reacted to horse movement, with their COM displacement matching that of the horse. The jockeys upper body muscles were instrumental in postural stability, damping the majority of horse oscillation, particularly in the medial/lateral and fore/aft planes. Jockey *quadriceps* activity reduced within and between rides, as core activation increased. The higher forces experienced in a galloping horse requires a higher intensity of work and potentially different muscles working in a different distribution and pattern than that experienced by jockeys riding track-work. The present results, in conjunction with future and present research of jockeys riding in races, provide insight into the needs of physical training for jockeys and hence the nature and content of a jockey specific physical conditioning programme.

6.8 References

Borg, G. A. V. (1982). Symposium: Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise,* 14: 377-381.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sport Physiology and Performance,* 12(Suppl 2): S2161-S2170. doi:10.1123/IJSPP.2017-0208

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

de Cocq, P., Muller, M., Clayton, H. M., & van Leeuwen, J. L. (2013). Modelling biomechanical requirements of a rider for different horse-riding techniques at trot. *Journal of Experimental Biology,* 216 (Pt 10): 1850-1861. doi:10.1242/jeb.070938

Dolan, E., O'Connor, H., McGoldrick, A., O'Loughlin, G., Lyons, D., & Warrington, G. (2011). Nutritional, lifestyle, and weight control practices of professional jockeys. *Journal of Sports Science,* 29(8): 791-799. doi:10.1080/02640414.2011.560173

Douglas, J. (2017). *Physiological Demands of Eventing and Performance Related Fitness in Female Horse Riders.* (Doctor of Philosophy), University of Worcester, UK.

Enoka, R. M., & Duchateau, J. (2008). Muscle fatigue: what, why and how it influences muscle function. *The Journal of Physiology,* 586(1): 11-23. doi:10.1113/jphysiol.2007.139477

Gonzalez, M. E., & Sarabon, N. (2020). Muscle modes of the equestrian rider at walk, rising trot and canter. *Plos One,* 15(8): e0237727. doi:10.1371/journal.pone.0237727

Horan, K., Kourdache, K., Coburn, J., Day, P., Brinkley, L., Carnall, H., Harborne, D., Hammond, L., Millard, S., & Pfau, T. (2021). Jockey perception of shoe and surface effects on hoof-ground interactions and implications for safety in the galloping Thoroughbred racehorse. *Journal of Equine Veterinary Science,* 97: 103327. doi:10.1016/j.jevs.2020.103327

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2020a). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi:10.1519/jsc.0000000000003514

Kiely, M., Warrington, G. D., McGoldrick, A., Pugh, J., & Cullen, S. (2020b). Physiological demands of professional flat and jump horse racing. *Journal of Strength and Conditioning Research,* 34(8): 2173-2177.

Kiely, M. A., Warrington, G. D., 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. doi:10.23736/S0022-4707.18.08196-3

Lee, J. T., Soboleswki, E. J., Story, C. E., Shields, E. W., & Battaglini, C. L. (2015). The feasibility of an 8-week, home-based isometric strength-training program for improving dressage test performance in equestrian athletes. *Comparative Exercise Physiology,* 11(4): 223-230. doi:10.3920/cep150018

Leger, L. A., Mercier, D., Gadouryl, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences,* 6: 93-101.

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Physical activities of jockeys during a working week. *Comparative Exercise Physiology,* 18(1): 75-83. doi:10.3920/cep210011

Macdermid, P. W., Fink, P. W., & Stannard, S. R. (2015). The effects of vibrations experienced during road vs. off-road cycling. *International Journal of Sports Medicine,* 36(10): 783-788. doi:10.1055/s-0034-1398534

Mester, J., Spitzenfeil, P., Schwarzer, J., & Seifriz, F. (1999). Biological reaction to vibration – implications for sport. *Journal of Science and Medicine in Sport,* 2: 211–226.

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., & Whitton, R. C. (2020a). Training practices, speed and distances undertaken by Thoroughbred racehorses in Victoria, Australia. *Equine Veterinary Journal,* 52(2): 273-280. doi:10.1111/evj.13156

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., Wong, A. S. M., & Whitton, R. C. (2020b). Variation in GPS and accelerometer recorded velocity and stride parameters of galloping Thoroughbred horses. *Equine Veterinary Journal*. doi:10.1111/evj.13370

Parkin, T. D. (2007). Havemeyer workshop report - Epidemiology of training and racing injuries. *Equine Veterinary Journal,* 39(5): 466-469. doi:10.2746/042516407x229233

Pfau, T., Spence, A., Starke, S., Ferrari, M., & Wilson, A. (2009). Modern riding style improves horse racing times. *Science,* 325(5938): 289. doi:10.1126/science.1174605

Pfau, T., Witte, T. H., & Wilson, A. M. (2005). A method for deriving displacement data during cyclical movement using an inertial sensor. *The Journal of Experimental Biology,* 208: 2503-2514. doi:10.1242/jeb.01658

Poon, E. T., O'Reilly, J., Sheridan, S., Cai, M. M., & Wong, S. H. (2018). Markers of bone health, bone-specific physical activities, nutritional intake, and quality of life of professional jockeys in Hong Kong. *International Journal of Sport Nutrition and Exercise Metabolism,* 28(4): 440-446. doi:10.1123/ijsnem.2016-0176

Pozzo, T., Levik, Y., & Berthoz, A. (1995). Head and trunk movements in the frontal plane during complex dynamic equilibrium tasks in humans. *Experimental Brain Research,* 106(2): 327–338.

Quintana, C., Grimshaw, B., Rockwood, H. E., Heebner, N. J., Johnson, A. K., Ryan, K. D., & Mattacola, C. G. (2019). Differences in head accelerations and physiological demand between live and simulated professional horse racing. *Comparative Exercise Physiology,* 15(4): 259-268. doi:10.3920/cep190005

Roberts, M., Shearman, J., & Marlin, D. (2010). A comparison of the metabolic cost of the three phases of the one-day event in female collegiate riders. *Comparative Exercise Physiology,* 6(3): 129-135. doi:10.1017/s1755254010000012

Rogers, C. W., & Firth, E. C. (2004). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 2. Measurement error and effect of training stage on the relationship between objective and subjective criteria of training workload. *New Zealand Veterinary Journal,* 52(5): 272-279. doi:10.1080/00480169.2004.36439

Spurway, N. C. (2007). Hiking physiology and the "quasi-isometric" concept. *Journal of Sports Sciences,* 25(10): 1081-1093. doi:10.1080/02640410601165270

Terada, K. (2000). Comparison of head movement and EMG activity of muscles between advanced and novice horseback riders at different gaits. *Journal of Equine Veterinary Science,* 11(4): 83-90. doi:10.1294/jes.11.83

Trowbridge, E. A., Cotterill, J. V., & Crofts, C. E. (1995). The physical demands of riding in National Hunt races. *European Journal of Applied Physiology,* 70(1): 66-69.

Vibert, D., Redfield, R. C., & Häusler, R. (2007). Benign paroxysmal positional vertigo in mountain bikers. *Annals of Otology, Rhinology and Laryngology,* 116(12): 887-890.

Visser, E. K., Van Reenen, C. G., Blokhuis, M. Z., Morgan, E. K., Hassmen, P., Rundgren, T. M., & Blokhuis, H. J. (2008). Does horse temperament influence horse-rider cooperation? *Journal of Applied Animal Welfare Science,* 11(3): 267-284. doi:10.1080/10888700802101254

Walker, A. M., Applegate, C., Pfau, T., Sparkes, E. L., Wilson, A. M., & Witte, T. H. (2016). The kinematics and kinetics of riding a racehorse: A quantitative comparison of a training simulator and real horses. *Journal of Biomechanics,* 49(14): 3368-3374. doi:10.1016/j.jbiomech.2016.08.031

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

7 Chapter Seven - Physiological demands and muscle activity of jockeys in trial and race riding.

Submitted in part in the following publication.

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of jockeys in trial and race riding. *Animals,* 12. doi:https://doi.org/10.3390/ani12182351.

7.1 Foreword to Chapter Seven

The previous chapter demonstrated that the physiological demands of riding track-work were low, with no evidence of fatigue during a typical morning workout. Jockeys adopted a crouched posture using their legs and arms as stabilisers, minimising their head movement in the medial/lateral and fore/aft planes. However, although track-work riding formed the majority of a jockeys training load, they also took part in trial and race rides weekly, and these demands were yet to be characterised. Therefore, the next step of this research was to determine the physiological demands, posture, and body displacements of a jockey riding in a trial or race. Determination of the differences, if any, between track-work, trial and race riding may be important in establishing the requirement for, and specifics of, exercises integral to a jockey specific competitive training programme.

7.2 Simple Summary

Jockeys are elite athletes and their performance during a race impact not only their own injury risk and career longevity, but also that of the horse they ride. The physiological parameters and muscle activity of jockeys during trials and races were quantified. This study found that trials act as a segue to race riding, with jockeys experiencing moderate to high intensity effort during a trial but using both their legs and (increasingly) arms to dampen horse oscillation. Jockeys riding races exercise at near maximal physiological potential, using only their legs to dampen horse oscillation in a lower crouched posture than that adopted by jockeys in trials, with their centre of mass (COM) shifted anteriorly. Therefore, the competition (race) level performance demands of the jockey are not only higher than training level demands, but jockeys assume a different riding posture. Achieving race specific fitness in readiness for competition is important for both horse and jockey safety, performance, and career longevity. Future physical training guidelines should aim to specifically target the physiological demands of race riding which are not exercised through training rides.

7.3 Abstract

Physiological parameters and muscle activity of jockeys may affect their fall and injury risk, performance and career longevity, as well as the performance and welfare of the horses' they ride. Therefore, this study aimed to quantify the physiological demands, body displacement and electromyographic (EMG) activity of twelve jockeys riding in 52 trials and 16 professional races. Jockeys were instrumented with heart rate (HR) monitors, accelerometers, and integrated EMG clothing (recording eight muscle groups: *quadriceps, hamstrings, gluteal, erector spinae/lower back, abdominal external obliques, abdominal, trapezial* and *pectoral*) which recorded continuously whilst riding.

On a competition day, jockeys rode an average of 5 ± 4 trials and 4 ± 2 races over 2 - 2.5 hours. Trials represented lower intensity cardiovascular demand (~81% HR_{max}) and Training Impulse scores (TRIMP, 4.4 ± 1.8) than races at maximal intensity effort (~94% HR_{max}, 7.2 ± 1.8 TRIMP, $p < 0.05$). Jockey head displacement was similar in trials (5.4 ± 2.1 cm) and races (5.6 ± 2.2 cm, $p > 0.05$), with more vertical (6.7 ± 2.7 cm) and less medial/lateral (2.3 ± 0.7 cm) and fore/aft (3.7 ± 1.6 cm) displacement for jockeys riding in trials than races (5.5 ± 2.3, 2.8 ± 1.0, 5.6 ± 2.5 cm, $p < 0.05$). Jockeys in races adopted a lower crouched posture, with their centre of mass (COM) shifted anteriorly, using greater *hamstring* activation and less upper arm muscle activation than trials. The differences in riding posture and physiological demand required by jockeys to ride in a race rather than a trial, highlight the requirement for an off-horse jockey specific training programme to improve jockey fitness and performance. Greater jockey stability and coordination will have mutual benefits for both horse welfare and performance.

7.4 Introduction

Jockeys have an integral role in the quality of racing and the welfare of the racehorse, so ensuring they are performing to their best potential is paramount not only for their own performance, injury risk and career longevity, but will also impact on the horses they ride. Securing a ride in a race, and winning, is the highest form of competition available to a jockey, with every race deemed of high importance due to pressure from trainers and owners, in addition to the prospect of individual financial awards and career progression (hopes of securing future rides). During racing, jockeys ride at close to their maximal physiological (aerobic and anaerobic) capacity (Cullen *et al.*, 2015; Kiely *et al.*, 2020b; Trowbridge *et al.*, 1995), supporting themselves in a crouched posture with only their toes in the stirrups, on a horse galloping at speeds exceeding 60 km·hr^{-1} (Warrington *et al.*, 2009). Continuous quasi-isometric muscle activity alterations in the jockey provides both postural support and dampens horse oscillation, with more experienced riders having greater postural control than novices (Terada, 2000; Terada *et al.*, 2004; Walker *et al.*, 2016). Measurement of the muscle activity and physiological parameters for top-level competitive conditions is rare in any form of sport, due to the (perceived) possibility of interference of the additional instruments with the jockey compromising their riding performance.

The riding schedule of an apprentice jockey in New Zealand follows the race preparation for horses and generally consists of approximately 2.5 hours riding multiple horses in "track-work" rides at 8 - 9 m·s^{-1} on 5 - 6 days a week, with a small proportion of fast workouts (gallop at > 14 m·s^{-1}) once or twice a week (Legg *et al.*, 2022; Morrice-West *et al.*, 2020; Parkin, 2007; Perkins *et al.*, 2005; Rogers *et al.*, 2004). Jockeys participate in jump out and trial sessions, as well as race meetings on 1 - 6 days a week (Legg *et al.*, 2021). Jump outs are unofficial training activities where groups of horses 'jump out' from starting gates and gallop a set distance, used primarily to improve horses' fitness through gallop training or to educate young horses and occur regionally once or twice a month. Trials are official mock races but without the pressure of result driven outcomes and are also hosted regionally once or twice a month. The aim of both is to gallop a horse under similar conditions to a race, and jockeys compete to obtain rides in both events, although they are not as financially important as race rides and have no weight restrictions for the jockey (catchweight). Distances are shorter, field sizes are smaller, and results are less important in jump outs and trials than races, with the emphasis on giving the horse the best ride possible, though jockeys are still expected to ride to their potential. In contrast, races are strictly controlled to ensure fair and competitive racing conditions where horses are allocated set weights to carry during a race, depending on the type of race and experience and quality of the horse. Apprentices may claim a 1 – 4 kg reduction (allowance) on the assigned weight of the horse, to compensate for their inexperience in race riding. The amount of the allowance reduces according to the number of winners the apprentice as ridden (thus can be used as a measure of experience). This allowance enables apprentices to obtain rides that otherwise may be preferentially offered to more experienced jockeys.

Understanding the sports competitive demands is the first step in building a specific training schedule to enhance performance in race riding. Training impulse (TRIMP) has been used as an integrative marker of exercise load undertaken by the athlete during training or competition and can be used as a comparative measure of exercise load (Padilla *et al.*, 2001). For track-work riding, TRIMP scores of 122 ± 67 for the entire session and 12 ± 6 per 5-minute ride have been reported (Legg *et al.*, 2022). Energy expenditure for a jockey riding at canter has been reported as 7.1 ± 1.8 $kcal \cdot min^{-1}$ corresponding to 7.7 metabolic equivalents (METs), lower than for jockeys in simulated races of 17.5 ± 2.3 $kcal \cdot min^{-1}$, and 9.4 METs (Cullen *et al.*, 2015; Kiely *et al.*, 2019). The physical exertion experienced by jockeys in their daily riding efforts are lower and considered to be insufficient to prepare a jockey for the maximal physiological demands of riding in a race (Kiely *et al.*, 2019). Therefore, a regular training schedule is important to meet the high specific physical demands of race riding.

Whilst there is a plethora of information about horse performance, less is known about the physiological demands of jockeys or how the jockeys' body displacement and muscle activity can influence horse performance or jockey fatigue and ultimately, race performance, injury risk and career longevity for jockeys during racing (Cullen *et al.*, 2015). Most jockeys do not follow a structured fitness programme but instead rely on the regular horses training schedules (including riding trials) as preparation for racing (Kiely *et al.*, 2020a; Legg *et al.*, 2021). Although the physiological demands and workload of jockeys riding in single races have been quantified, the demands of a jockey riding in multiple races and trials over the course of a single race day have not been examined.

Much of the study of jockey physiological parameters has been conducted during simulated races, however, it has been shown that jockeys work at lower intensity and experience lower accelerations in simulated vs. competitive races (Cullen *et al.*, 2015; Kiely *et al.*, 2020b; Quintana *et al.*, 2019). However, inevitably, what few guidelines exist for jockey training rely mainly on data from simulated races. Additionally, to the authors knowledge, muscle activity of jockeys has never been investigated in either simulated or competitive races and may be valuable tool in determining postural differences between training and racing, providing information for the formulation of future jockey training programmes. Jockey posture does vary between track-work and races (Legg *et al.*, 2022); therefore, quantification and comparison of the relative exercise intensity demands of a jockeys normal working schedule (racing preparation) is important to understand where and how a jockey specific physical training programme could be implemented. Therefore, the aims of this study were to quantify the physiological demands of jockeys over the course of an entire trial or race day, describe jockey body displacements and to profile the muscular activity of jockeys riding in trials and races.

7.5 Methods

7.5.1 Participants

Eight apprentice (5 male and 3 female) and four (2 male and 2 female) senior jockeys holding a current and valid licence with New Zealand Thoroughbred Racing (NZTR); the governing body for Thoroughbred racing in New Zealand, were recruited through NZTR. Apprentice jockeys held a current apprentice licence for 0.5 - 4 years and all had ridden in at least one race day ride. Senior jockeys had ridden professionally for 14 - 38 years. It was not possible to collect race data from apprentice jockeys due to their extra weight constraints (riding 1 - 4 kg below the allocated weight for the horse). Jockeys in New Zealand have a relatively homogenous riding style, with apprentice school tutors reinforcing a uniform technique. The majority of jockeys in New Zealand tend to ride with their toe in the stirrup iron, rather than the full foot. Written informed consent was obtained prior to commencement of data collection and only jockeys over the age of 18 years were considered for the study. Ethical approval for this study was provided by the Institutional Human and Animal Ethics Committees.

7.5.2 Data collection

Anthropometric data and predicted maximal aerobic capacity of the jockeys were assessed prior to (within 1 month) commencement of field data collection. Stature was assessed to the nearest cm using a portable stadiometer (Seca 213, Hamburg, Germany). Body mass was measured in minimal light clothing (shorts and shirt) using a portable digital weighing scales (Tanita InnerScan, Body Composition Monitor, BC-532). Body Mass Index (BMI) was calculated as the ratio of the weight to the square of height in metres ($kg \cdot m^{-2}$). Participants performed the multistage 20 m shuttle test (beep test) (Leger *et al.*, 1988) to determine their predicted maximal oxygen uptake (pred $\dot{V}O_{2\,max}$).

Field data were collected from jockeys instrumented with a number of physiological monitoring devices (described below) at jump outs, trials, and races. Jump outs were grouped with trials and hereafter are labelled as trials. All horses ridden were entered in the trial or race as part of their normal race training or competition schedule. All devices attached to the jockey were synchronised to universal time and recorded continuously from the jockeys first ride to the completion of the last ride. Data from each device were downloaded after the completion of the day's competition.

Speed, distance travelled, and heart rate (HR) of horse and jockey were determined using Polar human and equine HR monitors via Bluetooth to their respective watches (Polar V800 sports watch, Kempele, Finland) each containing a global positioning system (GPS) unit at a sampling rate of 1 Hz. Linear accelerations and displacements of horse and jockey were determined via synchronised wireless, tri-axial accelerometers with a reported accuracy 0.0012 $m{\cdot}s^2\ \sqrt{}\ Hz^{-1}$ (Emerald, APDM, OR, USA) and sampling rate 128 Hz, one attached to the horses' girth and one to the back of the jockey's helmet. Two additional accelerometers were attached to the jockey, one at the front of the jockey's pelvis, close to their centre of mass (COM) and one centrally between the shoulder blades (upper body). These had a sampling rate of 1000 Hz, rectified and averaged to 25 Hz (*Mytontec Muscle Monitor Version 3.1.1.3)*. Horse HR and accelerations were measured only for horses racing in trials due to strict NZTR racing regulations prohibiting any interference with regulated horse equipment.

Skin surface electromyography (EMG) was recorded via a specialised set of tightly fitting elasticised textile clothing (*Myontec*, Finland) worn under the clothes the jockey normally wore whilst riding in trials and races. The clothing contained embedded electromyographic (EMG) electrodes that afforded measurement of skin surface EMG (µV) of eight muscle groups (*quadriceps*, *hamstrings*, *gluteal*, *erector spinae/lower back, abdominal external obliques*, *abdominal*, *trapezial* and *pectoral*) at a sampling rate of 1000 Hz, filtered with 40 – 200 Hz (-3 dB) band-pass filters and digitalized with a 24-bit A/D converter and a Gain of 0. The 1000 Hz raw EMG signal was then rectified and averaged within the software programme (*Mytontec Muscle Monitor Version 3.1.1.3)* to 25 Hz. The EMG electrodes were moistened with water before the jockey donned the clothing to ensure adequate signal conduction. There were 2 sizes of EMG clothing, with the appropriate size matched to each jockey prior to data collection. The elasticised clothing was designed for a snug fit to conform to different shape and body types, and visually, there appeared to be good skin contact especially with the stretched electrodes over the lower back area, the *quadriceps* and *hamstrings*. The clothing was worn with braces to minimise textile movement and increase skin contact with electrodes over the upper body.

The time at which the jockey mounted, raced, and dismounted for each ride was manually recorded and subsequently matched to GPS data to identify the time of each race within the recorded data. Ride intensity was scored by the jockey after each ride using Borg's rating of perceived exertion (RPE) 10-point scale (Borg, 1982) and horse temperament was assessed by the jockey with a "Horse Contact" 10-point scale, where 1 represented a horse that requires strong urging forwards, 3 represented a horse that is 'on the bridle' (easiest to ride) and 10 a horse that they are unable to stop (Appendix E). The Horse Contact scale provided a simple measure of how tractable the horse was to ride, as this has been previously shown to affect the physiological demands of their jockeys (Kiely et al., 2019; Roberts et al., 2010).

7.5.3 Statistical analysis

Data were initially scanned for obvious errors and then summarised using descriptive statistics. Data were presented as means ± SD unless otherwise stated. Normality of data distribution was tested using the Shapiro Wilk's test. Differences between races and trials, beginning and end of rides, displacement axes and first and last rides were determined using Kruskal-Wallis and Wilcoxon rank sum tests for non-parametric data. One-and two- way repeated measures ANOVA comparisons were used to determine differences between displacements measured at different points on the jockeys' body both within and between rides. Cohen's effect size (ES) (Cohen, 1988) was calculated to determine differences between the appropriate groups by calculating the difference between the means divided by the pooled standard deviation. The scale suggested by Hopkins *et al.* (2009) classes an effect size of 0.2 as a small effect, 0.6 as a moderate effect, 1.2 as a large effect and 2.0 as a very large effect. TRIMP scores were calculated by summing the accumulated time (mins) spent in five different HR zones according to Edwards (1993). HR_{max} est was estimated as 220 – jockey age.

GPS data in combination with manually recorded data were used to determine the time spent riding or non-riding. Riding time began when the jockey mounted the horse and finished when the jockey dismounted on conclusion of the race, and consisted of a canter to the starting gates, racing, pulling up after the race and return to the parade ring. The trial or race portion was identified when the jockey was galloping at a velocity of ≥ 13.9 $m \cdot s^{-1}$ (Parkin, 2007; Rogers *et al.*, 2004), occurring < 10 s after leaving the starting gates and allowed calculation of jockey variables whilst travelling at steady state gallop. Three 200 m sectionals ("Start", "Middle" and "End") were extracted from the corresponding portion of each trial or race (gallop). These sectionals were used to summarise accelerometer and EMG data. Non-riding time was the time spent between dismounting after each ride and mounting the next horse and varied according to the individual jockeys' racing schedule.

Accelerometer data were filtered with a Butterworth low pass filter between 0.1 – 1.1 Hz to remove acceleration peaks. The magnitude of acceleration vector was calculated as the sum of squares of the three movement planes. The dominant frequency (the highest magnitude sinusoidal component of the acceleration signal, corresponding to the horses' stride frequency) of the cyclical movement of horse and jockey was by analysing the results of Fast Fourier Transform of the acceleration signal. Acceleration data were doubly integrated to quantify displacement following published methods (Pfau *et al.*, 2005). The delay of the time of the jockey and horse's point of vertical acceleration was measured for each stride averaging the time differences between the acceleration minima over a 200m sectional.

EMG signal power and dominant frequency were determined by Fourier Transform. Muscle activity was calculated by taking the mean signal recorded for each individual muscle as a percentage of the total signal recorded from all muscles investigated over the 200 m sectional. The left/right side balance was calculated as the percentage of left side muscle signal of the total signal for each muscle group (excluding *Abdominals* which was recorded across the centre of the muscle group). These methods were used in preference to the typical method of normalising EMG signal to a percentage of maximum voluntary contraction due to previous research suggesting that the typical method is inappropriate to describe the quasi-isometric riding position (Terada *et al.*, 2004). Additionally, the generalised EMG signal enabled only gross comparison between muscle groups, allowing the riding position in training, trials and races to be characterised, rather than specific analysis of each muscle group.

All statistical analyses were conducted using RStudio (version 3.5.1, 2018; R Foundation for Statistical Computing, Vienna, Austria) with the level of significance set at $p < 0.05$.

7.6 Results

Descriptive and mean anthropometric data for eight apprentice and four senior jockeys are presented in Table 7.1. Predicted $\dot{V}O_{2\ max}$ was assessed for all apprentice jockeys and two senior jockeys.

Table 7.1 Descriptive data (mean ± SD) for apprentice (n = 8) and senior (n = 4) jockeys

Variable	Apprentice	Senior	All
Age (yrs)	23 ± 3	41 ± 10	29 ± 10
Height (cm)	162.1 ± 5.4	159.9 ± 7.1	161.4 ± 5.4
Body Mass (kg)	51.5 ± 2.0	52.6 ± 1.9	51.9 ± 2.1
BMI ($kg{\cdot}m^{-2}$)	20.1 ± 0.9	20.7 ± 1.2	20.1 ± 0.9
Predicted $\dot{V}O_{2\ max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	45.1 ± 6.6	42.8 ± 6.4	44.6 ± 6.7

Race data were collected for senior jockeys only and complied with all NZTR racing regulations. Trial data were collected for all apprentice and two senior jockeys. Ridden horses included both male and female Thoroughbred horses in active race training, ranging from 2 - 10 years old and were entered in the trial or race on the day of data collection. Sixty-eight separate rides were recorded with 68 different horses. Of these, 52/68 rides were trials, and 16/68 rides were races. GPS and jockey HR data were recorded for n = 43/52 trials and n = 16/16 race rides. HR data for the horse were recorded for 7/52 trials. Accelerometer data for the horse were recorded for n = 32/52 trials. Accelerometer data for the jockeys' head were recorded for n = 48/52 trials and n = 10/16 race rides. EMG and accelerometer data for jockeys' upper body and COM were recorded for 48/52 trial rides and 16/16 race rides.

Jockeys rode a mean (± SD) of 5 ± 4 horses at trials and 4 ± 2 horses at the races. The jockeys' time allocation for trials and races and their corresponding HRs are shown in Table 7.2. Jockeys had less non-riding time between successive trial rides than at the races, with an average of 18.1 ± 22.6 minutes between rides at the trials (ranging from 0.5 - 94.1 minutes) and 38 ± 17 minutes (ranging from 24 - 66 minutes) between rides at the races ($p < 0.001$). The average HR of jockeys riding in a trial was ~81% HR_{max} and was ~60% HR_{max} for the entire time spent at the trials. The average HR of jockeys riding in a race was ~93% HR_{max} and was ~64% HR_{max} for the entire time spent at the races. The average (± SD) TRIMP score for the entire time spent by a jockey riding at trials was 200 ± 79 and 292 ± 106 at the races ($p = 0.1$). Mean horse HR_{peak} during a trial (n = 7) was 203 ± 22 bpm.

Table 7.2 Time allocation and HR (mean ± SD) during a day at the trials (n = 10) or races (n = 4) for 12 jockeys (n = 8 trials, n = 4 races).

Activity	Trials		Races	
	Time (minutes)	HR average (bpm)	Time (minutes)	HR average (bpm)
Entire Trials/Races	125 ± 58	119 ± 17	153 ± 94	114 ± 17
Non-riding	71 ± 43	115 ± 23	102 ± 73	98 ± 11
Riding	54 ± 20	140 ± 15	52 ± 23	130 ± 10
Trial/Race	5.5 ± 2.8	160 ± 17	6.1 ± 2.3	166 ± 10

The characteristics of work done by the horse and jockey (physiological response) per trial or race ride is shown in Table 7.3. Horses galloped faster in trials ($p < 0.05$) over shorter distances (ranging from 800 - 2,200 m) than races (ranging from 1,200 – 2,200 m, $p < 0.01$). Jockey HRs as percentages of estimated HR_{max} and TRIMP scores in trials were lower than for jockeys riding in a race ($p < 0.001$). The average RPE reported for a trial (3.6 ± 1.9, corresponding to moderate/somewhat hard intensity) was less than for a race (7.9 ± 2.4, corresponding to very hard intensity, $p < 0.001$), with no difference in RPE reported between the first and last ride of the day ($p = 0.4$ trials, $p = 0.2$ races). Horse Contact was 3.8 ± 2.2 for trial rides and 3.6 ± 2.0 for race rides ($p = 0.4$), both corresponding to marginal contact.

Table 7.3 Descriptive data (mean ± SD) of the characteristics of sectionals and entire trial (n = 52) and race (n = 16) rides and corresponding jockey physiological response per ride.

Descriptive (horse) variables	Trials				Races				
	Start	Middle	End	Entire Ride	Start	Middle	End	Entire Ride	ES+
Time (s)	11.6 ± 0.8*a	12.0 ± 1.0*b	12.4 ± 0.7*c	69.2 ± 19.8*	12.1 ± 0.3 a	12.7 ± 0.8 b	13.0 ± 0.5 b	91.4 ± 22.6	1.5
Distance (m)	200 ± 5*	200 ± 5	200 ± 4	1135 ± 276*	206 ± 3 a	201 ± 4 b	200 ± 5 b	1449 ± 303	1.5
Velocity ($m \cdot s^{-1}$)	17.4 ± 1.1*a	16.8 ± 1.2*b	16.2 ± 0.8*c	16.5 ± 0.8*	17.1 ± 0.4 a	15.9 ± 0.9 b	15.4 ± 0.5 b	16.0 ± 0.6	1.0
Stride count	27 ± 1a	28 ± 2 b	29 ± 2 b	-	28 ± 2 a	29 ± 2 b	29 ± 2 b	-	
Stride length (m)	7.4 ± 0.4a	7.1 ± 0.4 b	7.0 ± 0.4 b	-	7.5 ± 0.6 a	6.9 ± 0.4 b	6.8 ± 0.3 b	-	
Stride duration (s)	0.43 ± 0.02ab	0.42 ± 0.02*a	0.43 ± 0.02b	-	0.44 ± 0.03	0.43 ± 0.02	0.44 ± 0.02	-	
HR variables									
Mean HR (bpm)	149 ± 19 a	162 ± 18 b	172 ± 19 c	160 ± 17	151 ± 11 a	167 ± 11 b	178 ± 12 c	166 ± 10	0.6
Relative mean HR (%HR_{max} est)	76 ± 10%*a	83 ± 10%*b	87 ± 11%*c	81 ± 9%*	85 ± 3% a	94 ± 3% b	101 ± 3% c	94 ± 2%	2.5
Peak HR (bpm)	153 ± 20 a	167 ± 18 b	175 ± 18 c	177 ± 16	156 ± 12 a	170 ± 11 b	180 ± 11 c	182 ± 10	0.5
Relative peak HR (% HR_{max} est)	78 ± 11%*a	85 ± 10%*b	89 ± 9%*c	90 ± 9%*	88 ± 3% a	96 ± 2% b	102 ± 3% c	102 ± 2%	2.6
TRIMP	0.65 ± 0.21*a	0.83 ± 0.22*b	0.96 ± 0.21*c	4.42 ± 1.80*	0.89 ± 0.07 a	1.12 ± 0.10 b	1.16 ± 0.05 b	7.21 ± 1.83	2.2

+Effect Size (ES) between race and trial entire ride. Means differ ($p < 0.05$) between trial and race sectional (*) and across rows (abc) within each race type.

7.6.1 Accelerations and muscle activity

The dominant frequency (stride frequency) of the horse movement in trials was consistent in all planes at 2.3 ± 0.4 Hz. Jockey dominant frequency matched the horse in both races and trials at 2.3 ± 0.1 Hz ($p = 1$) and was consistent in all planes. Jockey movement preceded horse movement by 0.027 ± 0.051 seconds in trials. Jockeys experienced lower mean accelerations (16.1 ± 5.6 $m \cdot s^{-2}$ in trials and 15.8 ± 5.2 $m \cdot s^{-2}$ in races) and peak accelerations (25.3 ± 8.4 $m \cdot s^{-2}$ in trials and 28.1 ± 12.6 $m \cdot s^{-2}$ in races) than the horse (mean 37.5 ± 8.4 $m \cdot s^{-2}$, peak 68.9 ± 11.3

$m \cdot s^{-2}$ in trials, $p < 0.001$). Jockey acceleration in the vertical plane was approximately twice that of the medial/lateral and fore/aft planes in both trials and races (Appendix F).

The mean displacements and approximate riding position of the jockey at trials and races is shown in Figure 7.1. Displacements of jockeys riding at both trials and races were smaller than the displacement of a horse galloping at trials in all areas and planes ($p < 0.001$). Jockey head displacement was smaller in the vertical plane and larger in the medial/lateral and fore/aft planes for jockeys riding in races than in trials. The magnitude of jockey displacement in trials decreased from COM to neck to head ($p < 0.001$) with Cohen's effect size decreasing from very large 2.0 (horse - jockey COM) to moderate 0.6 (jockey COM - upper body) to small/moderate 0.5 (jockey upper body - head). In races, jockey COM displacement was greater than displacement at the upper body and head ($p < 0.001$). Cohen's effect size was large 1.2 between the jockeys' COM and neck with no difference (ES = 0.1, $p = 0.7$) between jockey upper body and head displacement in races.

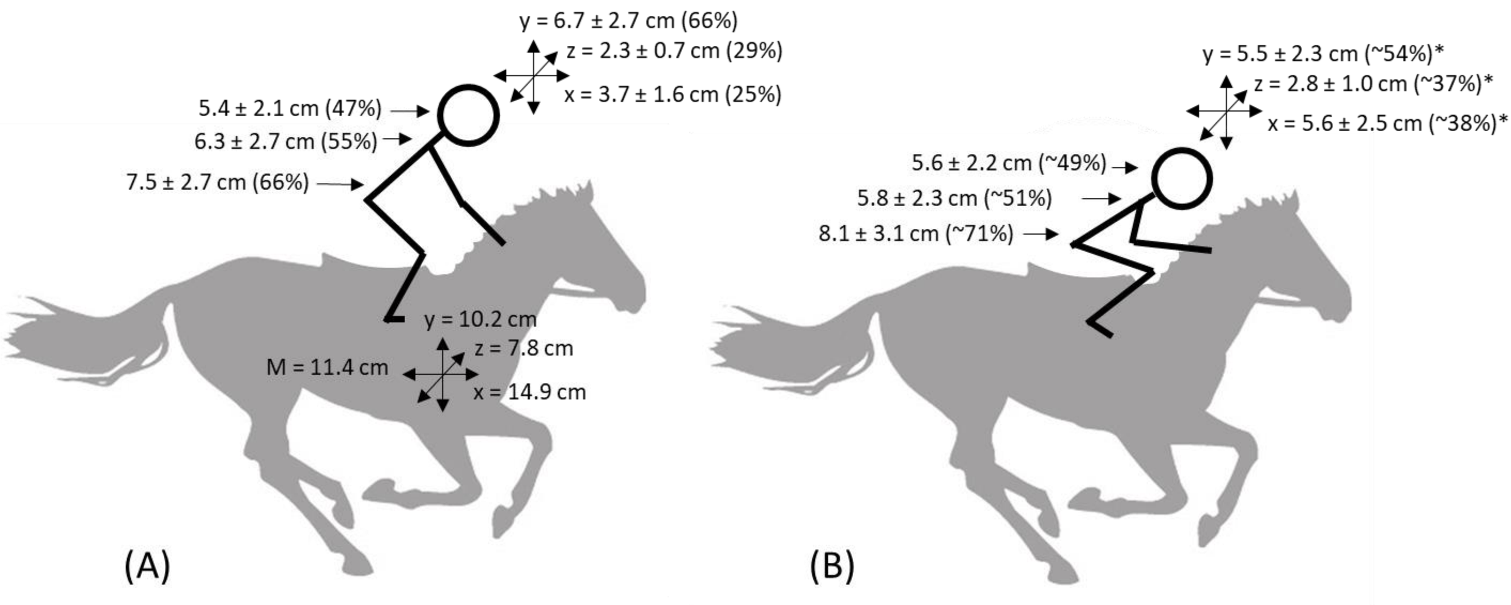

Figure 7.1 Mean magnitude (M) of displacements (cm) and relative displacement (%) of jockey to a horse galloping at (A) Trials and (B) Races, and in the vertical (y), fore/aft (x) and medial/lateral (z) planes. Horse displacements were measured only for horses racing in trials. All differences between jockey and horse (at trials) displacement are significant ($p < 0.05$). * denotes differences between jockey displacement in trials and races ($p < 0.05$).

Jockey COM displacement decreased within a trial ride. Jockey head displacement increased within both trial and race rides (Table 7.4). The difference in movement between jockey COM and head decreased within both a trial and race ride. Jockey COM and head displacement at the end of a race ride was greater than at the end of a trial ride.

Table 7.4 Mean (± SD) magnitude of displacements (m) of horse and jockey for within a trial (n = 48) or race (n = 16) and between the first and last ride (n = 10, trials, n = 4 races). Effect sizes are between horse displacement at trials and jockeys' head or start and end sectionals.

Riding Type	**Position**	**Within ride**				**Between rides**		
		Start	**Middle**	**End**	**Effect Size**	**First ride**	**Last ride**	**Effect Size**
Trials	Horse	0.110 ± 0.028^{1}	0.112 ± 0.029^{1}	0.121 ± 0.025^{1}	0.6	0.104 ± 0.025^{1a}	0.124 ± 0.024^{1b}	1.2
	Jockey COM	0.085 ± 0.039^{2a}	0.072 ± 0.017^{2ab}	0.068 ± 0.016^{23b}	0.8	0.075 ± 0.048^{2}	0.079 ± 0.025^{2}	0.1
	Jockey upper body	0.061 ± 0.035^{3ab}	0.061 ± 0.020^{3a}	0.068 ± 0.024^{2b}	0.3	0.066 ± 0.041^{2}	0.067 ± 0.024^{2}	0.0
	Jockey head	0.043 ± 0.015^{4a}	0.058 ± 0.021^{3b}	0.061 ± 0.023^{3b}	1.3	0.058 ± 0.029^{2}	0.058 ± 0.022^{3}	0.0
	Δ (horse - head)	0.067 ± 0.025	0.057 ± 0.031	0.063 ± 0.028	0.2	0.054 ± 0.031	0.065 ± 0.024	0.6
	Δ (COM - head)	0.043 ± 0.041^{a}	0.015 ± 0.027^{b}	0.007 ± 0.021^{b}	1.6	0.017 ± 0.056	0.024 ± 0.029	0.2
	ES (horse to head)	4.2	3.0	3.5		2.4	4.1	
Races	Jockey COM	0.082 ± 0.048^{1}	0.076 ± 0.012^{1}	0.085 ± 0.021*	0.1	0.095 ± 0.054^{1}	0.080 ± 0.020	0.5
	Jockey upper body	0.047 ± 0.024^{2a}	0.048 ± 0.012^{2a}	0.078 ± 0.018^{b}	2.1	0.064 ± 0.030^{2}	0.058 ± 0.023	0.3
	Jockey head	0.036 ± 0.004^{12a}	0.052 ± 0.013^{2b}	0.080 ± 0.017^{c*}	5.0	0.056 ± 0.021^{12}	0.067 ± 0.029	0.6
	Δ (COM - head)	0.062 ± 0.019^{a}	0.021 ± 0.007^{ab}	0.016 ± 0.005^{b}	4.7	0.047 ± 0.085	0.019 ± 0.026	0.6
	ES (horse to head)	~5.2	~3.8	~2.7		~2.9	~3.0	

Means with differing superscripts differ ($p < 0.05$) down columns within each riding type (^{123}), across rows (^{abc}) and between jockey riding at trials and races (*).

In both trials and races, the jockey's quadriceps muscle group was responsible for one quarter of the total muscle activity (Table 7.5). In trials, muscle activity was distributed evenly between the jockeys' legs *(quadriceps, hamstrings and gluteal,* 36%*)* and 'core' musculature *(lower back, obliques and abdominals,* 39%*)* with upper arm muscles *(trapezius and pectorals,* 26%*)* contributing one quarter of the total muscle activity. This distribution differed for jockeys riding in races, with half (51%) of total muscle activity in the jockeys' legs, with 'core' muscles contributing 35% and upper arm muscles only 14% of total muscle activity. The balance of muscle activity between the left and right sides of muscle groups was relatively even for jockeys at trials, with *obliques* and *trapezius* having a slight left bias. In trials, the lower body muscles *(quadriceps, hamstrings, gluteal)* were activated at a similar dominant frequency as the horse movement, whereas the lower back and upper body muscles had more variable dominant frequencies. In races, the *hamstrings* had a left side bias, and all jockey muscles had lower dominant frequencies than estimated for horse strides.

Table 7.5 Mean (± SD) surface EMG parameters of eight muscle groups for jockeys (n = 12) riding in trials (n = 48) and races (n = 16).

Muscle Group	**Trials**			**Races**		
	Muscle activity (%)	**Left/Right side balance (% Left side)**	**Dominant frequency**	**Muscle activity (%)**	**Left/Right side balance (% Left side)**	**Dominant frequency**
Quadriceps	23 ± 10^{a}	49 ± 9^{a}	2.0 ± 0.6^{a}	26 ± 13^{a}	51 ± 8^{a}	$1.8 \pm 0.7^{a*}$
Hamstrings	7 ± 4^{b}	49 ± 9^{ab}	2.0 ± 0.6^{a}	$21 \pm 15^{ac*}$	$64 \pm 15^{b*}$	$1.3 \pm 0.8^{ab*}$
Gluteal	6 ± 4^{c}	46 ± 9^{bd}	2.0 ± 0.7^{a}	$4 \pm 3^{b*}$	49 ± 13^{ac}	$1.5 \pm 0.8^{ab*}$
Lower back	15 ± 9^{d}	51 ± 10^{ac}	1.6 ± 0.8^{bc}	$19 \pm 11^{c*}$	51 ± 9^{a}	1.6 ± 0.8^{ab}
Obliques	16 ± 9^{d}	53 ± 13^{ce}	1.5 ± 0.7^{b}	$11 \pm 6^{d*}$	$49 \pm 8^{ac*}$	1.3 ± 0.8^{ab}
Abdominals	8 ± 6^{b}	-	1.5 ± 1.0^{bc}	$5 \pm 3^{b*}$	-	1.4 ± 0.9^{ab}
Trapezius	12 ± 9^{e}	54 ± 13^{e}	1.7 ± 0.8^{bc}	$5 \pm 5^{b*}$	$45 \pm 9^{c*}$	$1.3 \pm 0.9^{ab*}$
Pectoralis	14 ± 7^{d}	49 ± 9^{ad}	1.8 ± 0.7^{ac}	$9 \pm 5^{d*}$	53 ± 10^{a}	$1.2 \pm 0.8^{b*}$

^{abc} Values with different superscripts differ significantly within columns ($p < 0.05$) and between jockey riding at trials and races (*).

The percentage of muscle activity of the jockey *trapezius* muscle group increased between the first and last trial ride, and *abdominal* activity decreased between the first and last race ride (Table 7.6). Both within and between rides for each race type, there was little change in the distribution of jockey muscle activity. Upper arm muscles (*trapezius and pectorals*) contributed less and *hamstrings* more to overall muscle activity in all sectionals of race rides than in trial rides.

Table 7.6 Mean (± SD) muscle activity (%) of jockeys within a ride (n = 48 trials, n = 16 races) and between the first and last ride during trials (n = 48) and races (n = 16). Effect sizes are between the first and last sectional of the ride.

Riding Type	Muscle Group	Start	Middle	End	ES	First Ride	Last Ride	ES
Trials	*Quadriceps*	21 ± 8	23 ± 10	25 ± 11	0.7	25 ± 10	22 ± 10	0.4
	Hamstrings	7 ± 4	7 ± 4	7 ± 3	0.1	8 ± 5	7 ± 3	0.4
	Gluteal	6 ± 3	6 ± 3	6 ± 6	0.0	5 ± 2	5 ± 3	0.3
	Lower back	17 ± 10	15 ± 9	13 ± 7	0.6	15 ± 8	17 ± 12	0.3
	Obliques	16 ± 9	16 ± 9	15 ± 8	0.1	17 ± 11	15 ± 6	0.3
	Abdominals	8 ± 6	8 ± 5	7 ± 6	0.2	8 ± 8	10 ± 7	0.3
	Trapezius	10 ± 8	11 ± 9	13 ± 10	0.4	9 ± 3[a]	12 ± 6[b]	1.1
	Pectoralis	15 ± 7	14 ± 7	13 ± 6	0.5	14 ± 7	12 ± 4	0.5
Races	*Quadriceps*	27 ± 14	27 ± 14	24 ± 12	0.3	25 ± 13	24 ± 7	0.1
	Hamstrings	25 ± 17*	20 ± 15*	18 ± 13*	0.6	15 ± 11*	31 ± 18*	1.5
	Gluteal	4 ± 3	5 ± 3	4 ± 3	0.2	4 ± 2	3 ± 3*	0.2
	Lower back	19 ± 12	19 ± 13	20 ± 10*	0.2	21 ± 11*	21 ± 17	0.0
	Obliques	9 ± 6*	11 ± 5*	13 ± 6	0.8	11 ± 6	8 ± 3*	0.9
	Abdominals	4 ± 3*	6 ± 3	6 ± 4	0.8	8 ± 4[a]	3 ± 2[b]*	2.0
	Trapezius	4 ± 5*	5 ± 4*	7 ± 5*	0.7	8 ± 7	3 ± 3*	1.2
	Pectoralis	8 ± 5*	9 ± 5*	9 ± 5*	0.3	9 ± 5*	6 ± 2*	0.9

[abc] Values with different superscripts differ significantly across rows ($p < 0.05$) and between jockey riding at trials and races (*).

7.7 Discussion

To the authors knowledge, this is the first study to quantify the physiological demands, describe jockey body displacements and to profile the muscle activity of jockeys riding in both trials and races. In trials, which lasted 2 hours on average and involved multiple rides, jockeys had high HR's and exercised at a moderate to high aerobic intensity. In contrast, during a race day, which lasted 2.5 hours on average and also involved multiple rides, jockeys had near maximal HRs and near maximal aerobic demand during a race. In trial riding, jockeys adopted a crouched posture, using their legs to dampen horse oscillation using 'core and upper body muscles for postural control, with increased reliance on the arms for postural support after multiple rides. Jockey displacement was damped throughout the body, with medial/lateral and fore/aft movement of the head minimised. In contrast, during races, jockeys adopted a lower crouched posture, requiring increased *hamstring* activity to support their COM positioned anteriorly, damping horse movement mainly through both knee and hip, flexion and extension. Vertical displacement of the jockeys' head was lower and fore/aft displacement higher than for trials. In essence, they used their entire body for concurrent damping, postural control and to urge the horse to greater speeds.

Since the mean age of senior (race riding) jockeys was twice that of apprentice jockeys, relative measures of HR were used and are considered to provide a valid comparison method between trial and race rides. In races, the jockeys exercised at higher intensity than in trials. Their relative mean and peak HRs were similar to those previously reported in jockey's riding in races in Ireland, Hong Kong and United States (Cullen *et al.*, 2015; Kiely *et al.*, 2020b; O'Reilly *et al.*, 2017; Quintana *et al.*, 2019). This finding was reflected in the TRIMP scores, which were twice as high during races than for trials. For the duration of the event (all of comparable durations), the TRIMP of a jockey riding at the races (292 ± 106) was higher than at the trials and over twice that of riding track-work (122 TRIMP) (Legg *et al.*, 2022). Comparatively, the exercise load of a professional soccer player in a game lasting 1.5 hrs is ~190 TRIMP and for an athlete in a world class marathon race (~2 hrs) is ~275 TRIMP (Padilla *et al.*, 2001), though differences in sport specific variables such as eccentric muscular contractions are not taken into account in this measure. Between successive races there was some opportunity for the jockeys to rest and recover (25 - 30 mins between races). This time was spent speaking to trainers and preparing equipment to ride the next horse, requiring a low cardiovascular challenge, and may be a potential area to investigate rest and recovery strategies of experienced and novice jockeys. Thus, during a race meeting, jockeys experienced intermittent periods of intense cardiovascular load with sustained periods of elevated heart rate, similar to that observed in harness racing drivers (Nicols *et al.*, 2013). Between trials, the changeover between successive rides could be less than 1 minute, allowing little rest and recovery time between rides.

A jockey is required to balance and control the horse during the race, and horse temperament has been suggested as a contributor to the workload for the jockey (Devienne *et al.*, 2000; Legg *et al.*, 2022; Trowbridge *et al.*, 1995). However, in the present study, jockeys reported similar variation in horse contact during trials and races, indicating that when operating at maximal or near maximal capacity (both jockey and horse), horse temperament was not a significant factor in jockey workload. Horse contact is only one indicator of the temperament of the horse, so other behavioural indicators (such as a measure of 'fractious' behaviour') may be worth considering in future studies.

Jockey HR may have a psychological component, particularly in their non-riding time. Pressure from owners and trainers to perform well in a race, as well as personal pressure to obtain financial award and career opportunities, may all contribute to the elevated HR observed between races. Inspection of the jockey HR curve during the race showed that HR increased throughout the race, and peaked after race completion, implying that during a trial or race, jockey racing HRs were physiologically driven, rather than by an adrenal or stress response to the pressure of competition. Despite the high cardiovascular loads during trials and especially during races, most jockeys do not follow a structured fitness programme but rely on regular track work and riding horses in trials as preparation for racing (Kiely *et al.*, 2020a; Legg *et al.*, 2021).

Synchronous muscle activity throughout the jockeys' body damped external oscillation (horse movement), minimising movement of the jockeys' head. An analogous pattern of muscle activity has previously been observed in trackwork riders (Legg *et al.*, 2022) and cross-country mountain bikers (Macdermid *et al.*, 2014, 2015). In trials, head stability in the frontal plane was maintained, with 3 – 4 times less movement of the head than the horse in the medial/lateral and fore/aft planes. The magnitude of displacement of the jockey was greatest at their COM, decreasing towards their upper body and head, similar to jockeys riding track-work (Legg *et al.*, 2022). This was achieved by activating leg muscles (*quadriceps, hamstrings and gluteal*) in synchrony with the horses' movements. The lower dominant frequency of the 'core' muscles (*lower back*, *obliques* and *abdominals*) indicated their use in maintaining the postural stability of the jockey, with the upper arm muscles (*trapezius* and *pectorals*) in contact with the horses' neck aiding in the stabilisation of the jockey on the horse. Although there was little change in muscle group distribution of the jockey within a trial ride, their head movement increased, indicating that they may have had less control over the synchronous activity of their muscles towards the end of the ride, resulting in less damping of horse movement, a possible indication of neuromuscular fatigue. The increase in *trapezius* activity between the first and last trial ride could indicate that jockey became more reliant on using their hands on the horses' neck after riding multiple trial rides, another indication of the jockey feasibly mitigating the effects of fatigue. In contrast to track-work riding (Legg *et al.*, 2022), jockey movement in trials preceded that of the horse, indicating the jockey was moving more in synchrony with the horse and anticipating horse movement, as has been observed in more skilled dressage riders compared to novices (Gonzalez *et al.*, 2021; Lagarde *et al.*, 2005; Wolframm *et al.*, 2013).

The position of the jockey was subtly different between trials and races. The differences were pictorially exaggerated for clarity in Figure 1. Displacement of the jockeys' head in the vertical plane in race riding jockeys was lower than observed for jockeys riding in trials, indicating that the crouch posture of jockeys in a race was lower than for trials. This finding is consistent with the observation that, in vibration studies, smaller knee angles have been associated with reduced head accelerations (Munera *et al.*, 2016). The muscular activation profile of jockeys in races had a higher proportion of *hamstring* activity than jockeys riding in trials. The higher *hamstring* activation in race riding may be as a result of the lower 'crouched' position resulting in longer muscle length causing a greater activation of the *hamstring* muscle group to concurrently support jockey COM and damp horse motion. This indicates that jockeys in races balanced on their toes, closing their hip and knee angles with their COM lowered and shifted anteriorly. The larger ES (1.2) observed between the race riding jockey's COM and upper body displacement support the idea that horse movement was damped mainly by knee and hip - flexion and extension, controlled by the lower legs of the jockey in contact with the sides of the horse. This contrasts with a trial rider, having a wider knee and hip angle maintaining their COM and upper body more centrally over their feet, with a smaller difference between COM and upper body movement (ES = 0.6), similar to that observed in track-work jockeys (Legg *et al.*, 2022) and English riding in the two-point position (Peham *et al.*, 2010). This position would require less *hamstring* activity and less physiological (aerobic) work to maintain (Yanagisawa *et al.*, 2020). Additionally, trial riding jockeys may use their arms on the horses' neck to stabilise themselves, like the position adopted during track-work (Legg *et al.*, 2022), reducing the reliance on the *hamstrings*.

The magnitude of displacement of the race jockeys was greatest at their COM. This was similar for jockeys riding in track-work and trials, with additional damping occurring between the COM and upper body, but for race jockeys, there was no damping between the upper body and head. The posture of jockeys during races allowed greater damping of vertical horse oscillation but resulted in greater head movement in the medial/lateral and fore/aft planes than observed in trial riding jockeys. Thus, less work is required by the horse to move the mass of the jockey vertically through each stride cycle, potentially allowing the horse to achieve greater speeds (Pfau *et al.*, 2009). The weight distribution of a rider is an important aspect in the ability of a horse to move freely and easily (Fruehwirth *et al.*, 2004) and race jockeys appeared to have their weight positioned more anteriorly than trial and track-work jockeys, which perhaps allowed the horse to move more freely. Jockey head displacement in the fore/aft plane during races was 50% more than that of a jockey riding in trials and was likely due to the jockey enhancing momentum gains in optimised oscillations associated with their weight displacement, to positively encourage the horse to increase speed in the 'push' to the finish line.

Race riding jockeys used their arms and hands solely for directional control and urging the horse forward, resulting in a smaller proportion of upper arm muscle activity compared to trial riding jockeys. The dominant frequency of oscillation for all muscle groups of the jockeys were lower than that estimated for the horse. This indicated that muscles throughout the jockeys' whole body were not only responsible for postural damping of movement, but also functioned independently of the horses' movement, as the jockey both anticipated and influenced horse movement. This may have been a result of the jockeys racing strategy, whereby they were constantly adjusting the horses' pace and position in the race to optimise their opportunity to race to their maximum potential. Jockey head movement increased within a race. This may have been an indication of fatigue, resulting in less effective synchronous muscle activation, but was likely confounded by the additional activity of the jockey checking their position and urging the horse forwards in the final stages of the race. *Abdominal* activity was halved between the first and last race ride, indicating that this muscle group may have become fatigued in race riding jockeys, resulting in postural changes possibly reducing their riding effectiveness.

Track-work riding has been previously shown to demand a low to moderate physiological response in jockeys (Kiely *et al.*, 2019; Legg *et al.*, 2022). The present study has shown that trial riding demands a higher cardiovascular and muscular response, with race riding requiring maximal exertion. Thus, trial riding appears to act as a segue between track riding and race riding, even though the jockeys' posture is similar for both trial and track-work riding. Since trial riding requires less physical exertion and a different posture than that adopted by jockeys during a race, trial riding is likely to be insufficient preparation for race riding. Acquisition of both trial and race rides is largely dependent on a jockeys' skill and performance record, suggesting that apprentice jockeys may not be provided with ample opportunities to 'practice' and achieve race fitness. Indeed, using races themselves to acquire fitness implies that those jockeys are inadequately fit for racing, and the jockey would thus not be performing to their best potential at this highest level of competition. Jockeys who ride in races regularly and are assumed to be 'race fit' have greater success and lower injury risk (from falling) than the majority of jockeys who struggle to obtain multiple race rides (Legg *et* *al.*, 2020). Lower fitness has been associated with a higher risk of fall and injury in jockeys (Hitchens *et al.*, 2011), and the suggestion of fatigue in race jockeys could contribute to the higher fall risk seen in jockeys with few race rides. In New Zealand, it is common practice for jockeys to ride with only their toes in the stirrup iron, with the irons almost parallel to the side of the horse. Differences in foot placement in the stirrup may provide limited variation in the ability to attenuate displacement. However, the primary mechanism for damping horse movement is due to muscular activation of the jockey's proximal limb.

Advanced English riders have a higher ability to anticipate horse movement at a neuromuscular level with more defined and coordinated muscular activation patterns than novice riders, resulting in greater rider stability and synchronisation with the horse, which, in turn is associated with a lower injury risk to both horse and rider (Baillet et al., 2017; Gonzalez et al., 2020; Lagarde et al., 2005; Terada, 2000). A lack of synchronicity additionally results in greater energy expenditure in less experienced riders (Hobbs et al., 2020). Jockeys require a high level of baseline aerobic and anaerobic fitness, in addition to targeted exercises to improve neuromuscular control and co-ordination to improve and maintain on-horse stability and control. By improving the conditioning of jockeys, it is hypothesised that riding performance can be enhanced and the opportunity for jockeys to positively influence horses in race situations will increase. Therefore, the importance of sufficient race fitness of jockeys is not only to improve horse performance and welfare, but also jockey safety and longevity of career. The difference in posture and the maximal physiological demands required by jockeys to perform in a race, indicate that specific off-horse physical preparation to mimic the repeated high-intensity demands of race riding would be beneficial, especially to jockeys who are beginning their career, or who are rehabilitating or unable to acquire sufficient rides to achieve and maintain a racing level fitness.

7.7.1 Limitations

Attempting to collect data in the real world is fraught with difficulty, which resulted in an imbalanced study design, with apprentice jockeys clustered in the trial dataset and only senior jockeys in the race dataset. Due to the weight allowances of apprentice jockeys, these jockeys are under considerably more pressure to meet lower weight limits assigned to horses on race day. Participation in this study was voluntary and relied on good will, as jockeys were not contracted to participate in this trial. Therefore, data acquisition was dependant on the commercial reality of a jockeys' livelihood which was their primary consideration, rather than risking exceeding a weight limit and losing a ride. Difference in jockey experience between the two datasets was a confounder, however, there were no obvious differences in the magnitude or direction of displacements and EMG data between jockeys and apprentices within the trial data. The small number of jockeys within the trial dataset precluded logical statistical analysis within that dataset. However, based on the lack of differentiation between jockeys and apprentices during trial riding it would be unlikely that the differences between race and trial riding are solely due to jockey age or experience, given the obvious postural differences between trial and race riding.

The regulations of racing prohibit any intervention which may alter the outcome of the race. As such, monitoring of the participants was restricted to non-invasive or indirect measures. In flat racing, jockey weight is a method of handicapping horses, thus all equipment was required to be small, lightweight, and unobtrusive to the jockey. This allowed the jockey to make the correct weight assigned to the horse as well as ensuring unrestricted movement guaranteeing that there was no interference with the jockeys' capability to control the horse or limit final race placing. Additionally, jockey whip use, particularly in the final stages of the race, may confound results, perhaps resulting in greater jockey postural displacement or COM deviations. In New Zealand, the use of the whip is restricted to no more than five times prior to the final 100 m, after which it can be used at the jockey's discretion. However, there is tight judicial control over excessive use of the whip which effectively limits jockey medial/lateral displacements due to whip use in the final straight.

Whilst HR is a common means of monitoring physical activity intensity, it cannot measure metabolic rate and thus physical work requirement. Nevertheless, it does provide a good indicator of cardio-respiratory and vascular stress and, in the absence of any other measures, provides some insight into the physiological requirement of the sport by the jockey. Measuring the energy expenditure (as an indication of aerobic demands) and power output (as a measure of anaerobic demands) of jockeys and horses and how it could be used to determine optimal training as in other sports (cycling, rowing, running, kayaking) could be an interesting future avenue for study.

Both trials and races varied in distance, but on average races were longer than trials, which likely accounted for the higher speeds observed in trials than races. Thus, comparison of middle and end sectionals of an 850 m trial with a 2,200 m race may not be valid. It has been reported that the mean HR of a jockey in a long flat race (2,313 ± 142 m) was lower than in a shorter flat race (1,247 ± 185 m), but that there were no differences in peak HR, RPE or blood lactate concentrations (Kiely *et al.*, 2020b). Considering the difficulty in capturing data from multiple competitive rides, separating the results to compare races and trials of similar distances was not feasible in the present study.

7.8 Conclusions

Jockeys riding in trials and races experienced long periods (2 – 3 hours) of low – moderate intensity cardiovascular demand interspersed with periods of high or maximal physiological effort. Trial riding jockeys exercised at a lower intensity than race riding jockeys and activated their legs and arms to support and dampen horse oscillation, with 'core' musculature to maintain postural stability and minimise head displacement in the medial/lateral and fore/aft planes. Jockeys riding in races exercised near maximally in a lower crouched position, with a higher proportion of *hamstring* activation with their COM positioned anteriorly, using their legs, 'core' and upper body to both damp the oscillations and control the horse. This position resulted in lower vertical displacement of the head, but greater displacement in the medial/lateral and fore/aft planes than a trial riding jockey. The differences in cardiovascular demand and riding posture in jockeys riding in trials and competitive races indicate that there is a need for an off-horse jockey specific physical training programme to improve jockeys' race performance, which may be beneficial to jockeys overall riding safety and career prospects. Greater jockey stability and coordination will in-turn have mutual benefits for the horses' welfare and performance, ensuring both athletes perform to their maximum potential and enabling greater opportunity for jockeys to positively influence horses in race situations. Further research comparing jockey postural deviations and muscle activity with jockey experience, performance and after specific exercises may inform future assessment criteria for the development of safe and successful jockey education programmes in the racing industry.

7.9 References

Borg, G. A. V. (1982). Symposium: Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise,* 14: 377-381.

Cohen, J. A. (1988). *Statistical power analysis for the behavioural sciences* (2nd Ed. ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Devienne, M.-F., & Guezennec, C.-Y. (2000). Energy Expenditure of horse riding. *European Journal of Applied Physiology,* 82(5/6): 499-503. doi:10.1007/s004210000207

Edwards, S. (1993). High performance training and racing. In *The Heart Rate Monitor Book* (8th Edn ed., pp. 113–123). Sacramento, CA: Feet Fleet Press.

Fruehwirth, B., Peham, C., Scheidl, M., & Schobesberger, H. (2004). Evaluation of pressure distribution under an English saddle at walk, trot and canter. *Equine Veterinary Journal,* 36(8): 754-757. doi:10.2746/0425164044848235

Gonzalez, M. E., & Sarabon, N. (2020). Muscle modes of the equestrian rider at walk, rising trot and canter. *Plos One*, 15(8): e0237727. doi:10.1371/journal.pone.0237727

Gonzalez, M. E., & Šarabon, N. (2021). Shock Attenuation and Electromyographic Activity of Advanced and Novice Equestrian Riders' Trunk. *Applied Sciences,* 11(5). doi:10.3390/app11052304

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011). Are physiological attributes of jockeys predictors of falls? A pilot study. *BMJ Open,* 1(1): e000142. doi:10.1136/bmjopen-2011-000142

Hobbs, S. J., St George, L., Reed, J., Stockley, R., Thetford, C., Sinclair, J., Williams, J., Nankervis, K., & Clayton, H. M. (2020). A scoping review of determinants of performance in dressage. *PeerJ*, 8: e9022. doi:10.7717/peerj.9022

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise,* 41(1): 3-13. doi:10.1249/MSS.0b013e31818cb278

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. J. (2020a). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi:10.1519/JSC.0000000000003514. Epub ahead of print.

Kiely, M., Warrington, G. D., McGoldrick, A., Pugh, J., & Cullen, S. (2020b). Physiological demands of professional flat and jump horse racing. *Journal of Strength and Conditioning Research,* 34(8): 2173-2177.

Kiely, M. A., Warrington, G. D., 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. doi:10.23736/S0022-4707.18.08196-3

Lagarde, J., Kelso, J. A., Peham, C., & Licka, T. (2005). Coordination dynamics of the horse-rider system. *Journal of Motor Behavior,* 37(6): 418–424.

Leger, L. A., Mercier, D., Gadouryl, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences,* 6: 93-101.

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of "track-work" riding in apprentice jockeys. *International Journal of Sports Physiology and Performance* (In press*)*.

Legg, K., Cochrane, D., Gee, E., & Rogers, C. (2020). The external workload of Thoroughbred horse racing jockeys *Sustainability,* 12. doi:https://doi.org/10.3390/su12187572

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Physical activities of jockeys during a working week. *Comparative Exercise Physiology,* 18(1): 75-83. doi:10.3920/cep210011

Macdermid, P. W., Fink, P. W., & Stannard, S. R. (2014). Transference of 3D accelerations during cross country mountain biking. *Journal of Biomechanics,* 47(8): 1829-1837. doi:10.1016/j.jbiomech.2014.03.024

Macdermid, P. W., Fink, P. W., & Stannard, S. R. (2015). The effects of vibrations experienced during road vs. off-road cycling. *International Journal of Sports Medicine,* 36(10): 783-788. doi:10.1055/s-0034-1398534

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., & Whitton, R. C. (2020). Training practices, speed and distances undertaken by Thoroughbred racehorses in Victoria, Australia. *Equine Veterinary Journal,* 52(2): 273-280. doi:10.1111/evj.13156

Munera, M., Bertucci, W., Duc, S., & Chiementin, X. (2016). Transmission of whole body vibration to the lower body in static and dynamic half-squat exercises. *Sports Biomechanics,* 15(4): 409-428. doi:10.1080/14763141.2016.1171894

Nicols, L., Rogers, C. W., Stannard, S., Tanner, J. C., & Bridges, J. (2013). The effect of harness racing on the heart rate of professional harness racing drivers. *Comparative Exercise Physiology,* 9(2): 79-83. doi:10.3920/cep13012

O'Reilly, J., Cheng, H. L., & Poon, E. T.-C. (2017). New insights in professional horse racing; "in-race" heart rate data, elevated fracture risk, hydration, nutritional and lifestyle analysis of elite professional jockeys. *Journal of Sports Sciences,* 35(5): 441-448. doi:10.1080/02640414.2016.1171890

Padilla, S., Mujika, I., Orbananos, J., Santisteban, J., Angulo, F., & Goiriena, J. (2001). Exercise intensity and load during mass-startstage races in professional road cycling. *Medicine and Science in Sports and Exercise,* 33: 796–802.

Parkin, T. D. (2007). Havemeyer workshop report - Epidemiology of training and racing injuries. *Equine Veterinary Journal,* 39(5): 466-469. doi:10.2746/042516407x229233

Peham, C., Kotschwar, A. B., Borkenhagen, B., Kuhnke, S., Molsner, J., & Baltacis, A. (2010). A comparison of forces acting on the horse's back and the stability of the rider's seat in different positions at the trot. *The Veterinary Journal,* 184(1): 56-59. doi:10.1016/j.tvjl.2009.04.007

Perkins, N. R., Reid, S. W. J., & Morris, R. S. (2005). Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *New Zealand Veterinary Journal,* 53(1): 59-68.

Pfau, T., Spence, A., Starke, S., Ferrari, M., & Wilson, A. (2009). Modern riding style improves horse racing times. *Science,* 325(5938): 289. doi:10.1126/science.1174605

Pfau, T., Witte, T. H., & Wilson, A. M. (2005). A method for deriving displacement data during cyclical movement using an inertial sensor. *The Journal of Experimental Biology,* 208: 2503-2514. doi:10.1242/jeb.01658

Quintana, C., Grimshaw, B., Rockwood, H. E., Heebner, N. J., Johnson, A. K., Ryan, K. D., & Mattacola, C. G. (2019). Differences in head accelerations and physiological demand between live and simulated professional horse racing. *Comparative Exercise Physiology,* 15(4): 259-268. doi:10.3920/cep190005

Roberts, M., Shearman, J., & Marlin, D. (2010). A comparison of the metabolic cost of the three phases of the one-day event in female collegiate riders. *Comparative Exercise Physiology*, 6(3): 129-135. doi:10.1017/s1755254010000012

Rogers, C. W., & Firth, E. C. (2004). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 2. Measurement error and effect of training stage on the relationship between objective and subjective criteria of training workload. *New Zealand Veterinary Journal,* 52(5): 272-279. doi:10.1080/00480169.2004.36439

Terada, K. (2000). Comparison of head movement and EMG activity of muscles between advanced and novice horseback riders at different gaits. *Journal of Equine Veterinary Science,* 11(4): 83-90. doi:10.1294/jes.11.83

Terada, K., Mullineaux, D. R., Lanovaz, J., Kato, K., & Clayton, H. M. (2004). Electromyographic activity of the rider's muscles at trot. *Equine and Comparative Exercise Physiology,* 1(3): 193-198. doi:10.1079/ECEP200420

Trowbridge, E. A., Cotterill, J. V., & Crofts, C. E. (1995). The physical demands of riding in National Hunt races. *European Journal of Applied Physiology,* 70(1): 66-69.

Walker, A. M., Applegate, C., Pfau, T., Sparkes, E. L., Wilson, A. M., & Witte, T. H. (2016). The kinematics and kinetics of riding a racehorse: A quantitative comparison of a training simulator and real horses. *Journal of Biomechanics,* 49(14): 3368-3374. doi:10.1016/j.jbiomech.2016.08.031

Warrington, G., Dolan, E., McGoldrick, A., McEvoy, J., MacManus, C., Griffin, M., & Lyons, D. (2009). Chronic weight control impacts on physiological function and bone health in elite jockeys. *Journal of Sports Sciences,* 27(6): 543-550. doi:10.1080/02640410802702863

Wolframm, I. A., Bosga, J., & Meulenbroek, R. G. J. (2013). Coordination dynamics in horse-rider dyads. *Human Movement Science,* 32(1): 157-170. doi:10.1016/j.humov.2012.11.002

Yanagisawa, O., & Fukutani, A. (2020). Muscle recruitment pattern of the hamstring muscles in hip extension and knee flexion exercises. *Journal of Human Kinetics,* 72: 51-59. doi:10.2478/hukin-2019-0124

8 Chapter Eight – General discussion and conclusions

The training and competitive workloads of jockeys have been examined in detail in this thesis. As hypothesised in Chapter 2, jockey inexperience and fatigue are associated with an increased risk of jockey falls during competitive racing. However, Chapter 3 showed that jockeys with higher competitive workloads perform better, have fewer falls and longer, safer, and more successful careers than those with lower competitive workloads. The disparity in opportunity and success between high and low workload jockeys indicate that there are inefficiencies within the industry in recruitment and retention of jockeys (Chapter 4). Chapter 5 showed that elite jockeys experience a level of race specific exercise which is lacking in the majority of jockeys. Jockeys who are 'fitter' are less likely to fall on race-day.

Chapter 6 showed that jockeys used riding (track-work, trials and races) as the main training exercise to achieve race fitness. Track-work requires a low physiological (aerobic) demand with no evidence of fatigue. Chapter 7 indicated that trial riding requires a moderate physiological demand, whereas race riding requires near maximal demand, and a lower crouched posture with a different muscular activation profile than jockeys riding in track-work and trials. The differences in physiological demands between trial and race riding jockeys are similar to the physiological demands observed for jockeys in overseas jurisdictions (Kiely *et al.*, 2020; Kiely *et al.*, 2019; Ryan *et al.*, 2021). Contrary to hypothesis, the differences in body displacement and muscle activity of jockeys highlight the differences between riding in training and competition and give unique insight into the position and muscle action of the jockey on-horse. The inability of unskilled jockeys to obtain sufficient trial or race rides underlines the need for an off-horse jockey specific physical training regime to improve both safety and performance in jockeys (as indicated in Chapters 2 - 5). The long latency in development of the required skills may be reduced by appropriate exercises to develop the neuromuscular coordination of muscular activation patterns observed in senior race riding jockeys. Instigation of a race-specific physical training programme (using physiological parameters from Chapters 6 – 7) early in the career of an apprentice jockey, with clearly defined milestones, would be likely to help increase retention of high-quality jockeys within the industry as well as help improve both horse and jockey welfare and performance.

Jockeys face a ubiquitous dilemma where they compete to obtain both trial and race rides, with success determined by their performance and skill in each ride. However, riding itself is a source of injury risk, with most jockeys reporting multiple falls during training rides in a 12-month period (Chapter 5, (O'Connor *et al.*, 2020). Greater physical fitness (to delay the onset of fatigue) would allow jockeys to use their riding skills to the best of their ability, resulting in safer, more effective riding with (hopefully) better cognisant decision making during a race (Moore *et al.*, 2012; Ryan *et al.*, 2021; Wilson *et al.*, 2014). If a strong basal level of fitness could be achieved by supplementation of race-rides with off-horse specific training, this may result in a safer sport for both jockey and horse. As 14 - 40% of jockey falls result in injury (Bolwell *et al.*, 2014; Davies *et al.*, 2021; O'Connor *et al.*, 2020; Turner *et al.*, 2002), an appropriate training programme could focus on maintaining conditioning aspects relevant for those jockeys that have succumbed to injury. The following sections detail the jockey relevant considerations in creation and use of a race-specific training programme.

8.1 Physical training

Training load is important for all athletes, both to improve the body's tolerance to increasing loads, and to develop the physical qualities (e.g., strength, endurance and aerobic fitness) that are associated with a reduced injury risk from physical activity (Bourdon *et al.*, 2017). The importance of physical fitness in reducing the effects of fatigue was suggested in Chapter 5, where jockeys who participated in extra (off-horse) physical training had lower risk of race-day falls.

Physical training is beneficial only if it overloads the body in such a way as to stimulate adaptation (Bompa *et al.*, 2009). Race-riding requires higher aerobic demand (Kiely *et al.*, 2019) and postural adjustments not evident in training rides (Chapters 6 - 7). As adaptation is highly specific to the type of training undertaken, the training must be specific to the energy systems, skills and motor abilities required by the particular activity. It appears that higher numbers of race rides not only increase the chance of jockey success, but the higher frequency of race riding may increase the "competition fitness" of jockeys and reduce the risk of injury. However, if training load is too high and undertaken for excessively long periods of time, injury or overtraining may occur (Bompa *et al.*, 2009; Kellmann, 2010). This effect was seen to some extent with the increased chance of falling with increasing races ridden per day (Chapter 2) indicating that fatigue (mental and physical) may also play a role in race day falls.

Jockeys face continuous psychological and time pressures to maintain a busy racing schedule, obtain rides and work closely with the differing constraints of owners, trainers and even the horses themselves (King *et al.*, 2021; Losty *et al.*, 2019). Therefore, jockeys additionally may need to plan time to reduce their mental overloading and 'de-stress' through the appropriate principles of rest, recovery, and regeneration to optimise their performance (Bompa *et al.*, 2009; Halson, 2014). This thesis provides the beginnings of a comparative workload index (using the TRIMP concept, (Padilla *et al.*, 2001)) which characterises both training and competition physical load in jockeys, from which a tailored training programme for jockeys could be designed.

8.1.1 Optimum training load

Based on the findings of this thesis, the majority of jockeys are lacking the high intensity physiological demand and higher frequency of race-rides (training load) of the elite jockeys. Additionally, jockeys who take part in fewer races are not exposed to the particular set of neuromuscular skills (reaction and coordination), a vital part of the competition specific skill set (race tactics) required by jockeys to ride in a race. Although physiological load was the primary focus of this thesis, total training load is multifactorial, encompassing multiple biological constraints (Gabbett, 2020a). The biological constraints not investigated in this thesis may also contribute to injury risk from high training loads, and include age, phenotype, previous injury history, chronic load, experience, psychological factors and physical and mental fitness (Gabbett, 2020a; Gabbett, 2020b). These factors highlight the importance of determining the optimum training load for athletes, below which the body is 'unfit' for the pressures of competition, and above which the risk of injury increases exponentially, due to 'overtraining' (Bourdon *et al.*, 2017). To have a sustainable and successful career as a jockey within the racing industry, these factors must be balanced in order to optimise and sustain jockey performance. The studies in this thesis provide quantitative workload metrics for jockeys, which could be used to model the threshold required to reach race-riding competency and for the development of a jockey specific training programme.

Athlete development models recognise the importance of the foundational requirements of aspiring athletes to acquire basic fitness and proprioceptive skills before specialising in their chosen sport (Gulbin *et al.*, 2013b). The pathway for jockeys to achieve and maintain success in racing ideally follows that proposed for human athletes in high-performance sports (Balyi *et al.*, 2004). This model maintains a progressive (though non-linear) development pathway linked to the athlete's needs, goals, and stage of development with the sport. Development of fundamental movement skills and sport specific skills is required before expanding the physical and mental capabilities required to compete successfully in high performance sport.

The findings of the present thesis have made it possible to propose the development of a new model of training load and athlete development which is specific to jockeys (Figure 8.1). This illustrates the proposed conceptual framework underpinning the relationship between training load (encompassing number of races and biological constraints) and jockey experience (licensing milestones) to optimise race performance in jockeys to maintain a successful and sustainable career in race riding. The new model is based on, and is an extension of, the long term elite athlete development model (Balyi *et al.*, 2004). In the proposed new model, jockeys progress from requiring a high training load (but lower intensity) of basic physical literacy skills (Active Lifestyle) and riding skills (FUNdamentals), to learning to ride in the jockey 'crouch' posture. Once basic riding fitness is achieved (Learning to Ride), the skills of riding multiple different horses at race speed require practice and training to become instinctive (Riding to Train), thus allowing the jockey the focus and ability to execute tactical maneuvers during the race (Riding to Compete). At this point, the jockey requires a lower training load (but high intensity) to maintain and hone their established physical, technical, tactical and mental competition fitness (Riding to Win).

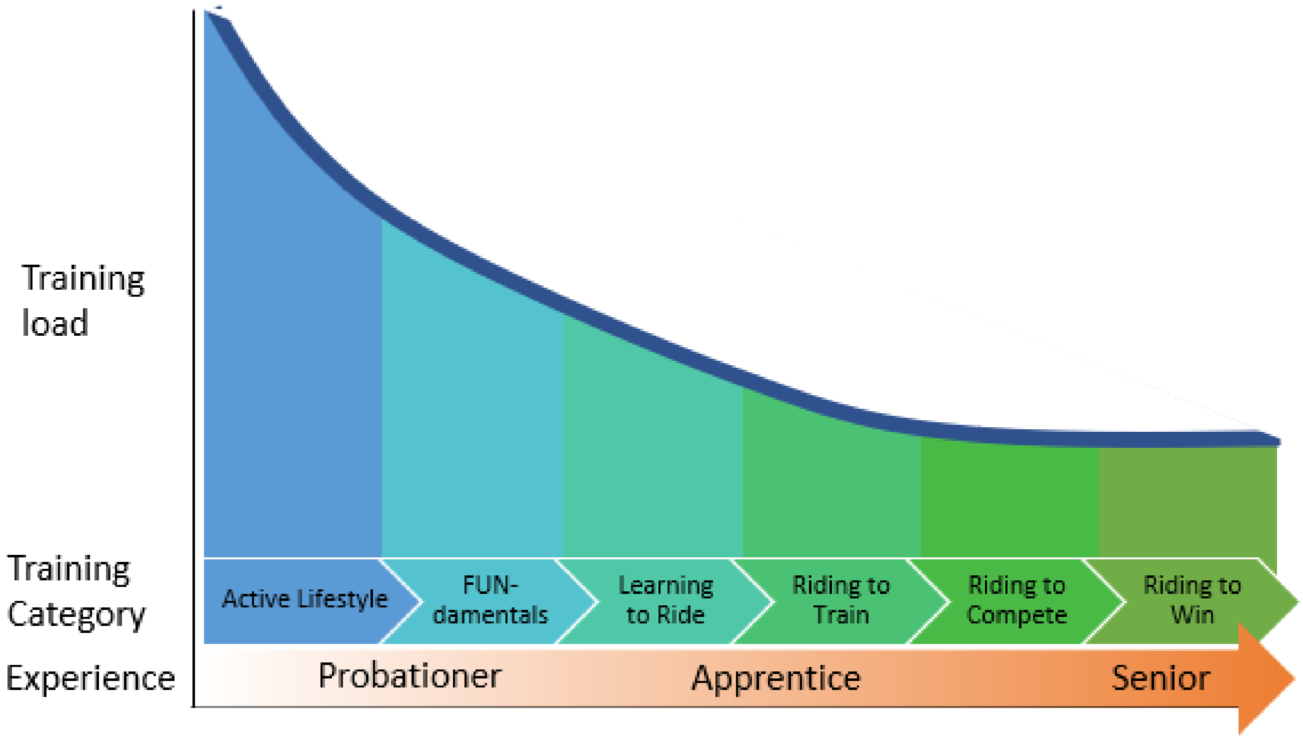

Figure 8.1 Conceptual framework model of the relationship between training load and jockey experience based on the athlete development pathway to optimise a successful and sustainable career in jockeys. (Legg, 2022, adapted from Balyi *et al.* (2004)).

Determination of this theoretical threshold level of race-specific fitness or training load, based on the frequency threshold of training and race rides, could provide important metrics required by jockeys to balance the multiple factors of physical fitness, race-specific skills and psychological stressors. The studies in Chapters 2 – 5 indicate that jockeys able to achieve this theoretical threshold experience both safer racing (less falls and thus lower injury risk), greater success and longer careers. An analogous threshold has been observed in elite rugby players, with players involved in 15 – 35 competitive matches at a lower risk of injury in the subsequent season than players both below and above this threshold (Williams *et al.*, 2017). Planning appropriate training load and management of loading patterns is important to guarantee a long sporting career (Bourdon *et al.*, 2017; Kellmann, 2010; Ryan *et al.*, 2021), with only a small proportion of jockeys achieving this success (Chapter 4). This highlights the importance of providing early training and race exposure opportunities to apprentice jockeys, which may help to establish effective work and fitness practices and routines (Gulbin *et al.*, 2013b). These routines may be essential in forming the basis of a long and successful career in racing, as discussed in the following section.

8.2 Career pathway

The data presented in this thesis could be used to determine the optimum number of jockeys required by the industry to maintain the current level of Thoroughbred racing in New Zealand. Limiting the numbers of apprentice jockeys to maintain a target number of working jockeys, though stricter selection criteria (based on the consistency of anthropometric limitations of jockeys), may allow more intensive investment into the training and education of new apprentices. Additionally, if an optimum number of professional jockeys were maintained, the pressure to obtain rides, a major concern for all professional jockeys (Losty *et al.*, 2019), would be reduced. In association with a specialised apprentice training programme, these measures may help to retain and support jockeys in their career.

The studies presented in Chapters 2 - 4 indicate that the length of a typical jockey's career is very short at only 2 years, and is heavily influenced by the ability to obtain race rides early in their career. Specialised apprentice training has been shown to be effective in Australia where a structured training programme for apprentices reduced the annual rate of loss of apprentices from 25% to 10% (Speed, 2001). Indeed, jockeys who began their career at a younger age were more likely to stay in their careers for longer (Chapter 4). Instigation of apprentice only races may be one avenue to provide the less experienced apprentice jockeys more opportunities to obtain race rides.

The disparity in opportunity and success between jockeys within the high and low workload cohorts (Chapters 3 - 4) indicate there are inefficiencies within the Thoroughbred racing industry both in recruitment and retention of jockeys. Currently, an apprentice jockey's ability to progress from track- to trial- to race-riding are assessed through riding competency (and thus, by proxy, physical fitness) in training and trial rides.

Motor skill in sport is inextricably linked with physical fitness, with decreases in both proprioceptive and cognitive ability observed after physical fatigue (Abd-Elfattah *et al.*, 2015; Moore *et al.*, 2012; Stodden *et al.*, 2009). However, riding competency in training rides, though a reasonable indicator of physical fitness and jockey ability, may not provide adequate physiological preparation for aspiring jockeys to compete to their best potential at the beginning of their careers. Chapters 6 – 7 have identified differences in head movement during riding that may be used as guidelines to quantify jockey on-horse stability and to assess the skill and preparation of jockeys to achieve apprenticeship milestones and compete safely in races.

Jockeys in New Zealand traditionally do not think of themselves as athletes. However, the demands of their profession at professional level could be considered similar to elite level sports performance. Understanding the development pathway of a top-level athlete is important to the long-term sustainability of an elite sporting career (Gulbin *et al.*, 2013a; Kellmann, 2010). To produce and retain elite quality athletes within the industry, a holistic approach, with emphasis on educating young athletes on nutrition (Ryan *et al.*, 2021), physiology and lifestyle, as well as support with psychological demands (King *et al.*, 2021; Losty *et al.*, 2019) of the sport may be required. The 'Pathway to Podium' athlete development programme is a nationwide initiative run in partnership between Sport New

Zealand, High Performance Sport New Zealand, National Sports Organisations, and Regional Talent Hubs to help better prepare emerging athletes and coaches for the demands of a life in high performance sport. Participants receive support including funding, and access to local training facilities as well as educational workshops on all aspects of athlete development, and an individual performance plan to help prepare for the demanding lifestyle of a professional athlete.

Currently, apprentice training is mainly reliant on trainer discretion, resulting in wide differences in the support available to a jockey, particularly in the acquisition of trial and race rides. Apprentice jockeys are at a similar stage in their career as young athletes selected for 'Pathway to Podium' in other sports, and a logical consequence of the findings of the present thesis would be to recommend that the apprentice jockey programme uses a similar model to provide support to reach and maintain peak performance as that received by high performance athletes in other sports. A similar programme would provide young jockeys with measurable milestones within the industry to assess their progress and achieve success.

8.3 Strengths and limitations

This is the first comprehensive series of related studies investigating the physiological demands of a cohort of jockeys in training and race riding. It has used multiple methods to explore jockey workload, both in their long-term performance, success and career length, and the specific individual ride level demands of training and competitive race rides.

Racing is unique as a sport where male and female athletes compete in the same race, and both must compete within the same set maximum weight restrictions. The lack of gender bias in race riding opportunities and ability to compete at top level in New Zealand make this dataset unique. Male and female jockeys were represented in approximately equal numbers in every study within the thesis. However, the obvious differences in phenotype and body composition between male and females may provide different physiological challenges when riding and when fasting to meet weight requirements and hence vary the onset of fatigue with cumulative effort. Additionally, male riders have been reported to have a more neutral position on the horse than female riders (with a posteriorly rotated pelvis), indicating they have a biomechanical advantage when riding in the English style (Bye *et al.*, 2022). These differences were considered to be minimal when investigating long term epidemiological trends, relative physiological demands and overall riding postural differences between training and race rides in cohorts containing relatively equal numbers of male and female jockeys.

Current and long-term trends of jockey falls, workload and career variables were described using 14 years of consistent longitudinal race-day data. However, these data did not include information regarding jockey training, and only rudimentary anthropometric or performance level variables pertaining to the jockeys were able to be inferred from the dataset. Despite this deficit, the size and comprehensiveness of the dataset provided reliable metrics relating to the competition level workload of jockeys.

Quantification of physiological parameters and muscle activity of athletes at top level competition in any sport is rare. The studies described in Chapters 6 – 7 used multiple devices to measure jockey physiological demand, body displacement and muscular activity during both training and top-level competition. To comply with racing regulation and weight restrictions, as well as to allow jockeys freedom of movement whilst riding, these devices were required to be small, light, and unrestrictive. In addition, devices attached to horses were also required to be small, unobtrusive, and able to be attached and removed quickly to minimise the impact these devices may have on young and highly-strung competition-ready horses. The accelerometer measuring horse accelerations during track-work and racing in Chapters 6 – 7 was placed on the left side of the horses' girth, rather than centrally underneath the horse, as in other studies (Barrey *et al.*, 1997; Horan *et al.*, 2021). Time and practical restraints (e.g., handling young, energetic racehorses) limited the ability to place the unit accurately underneath the horse, so it was considered reasonable to consistently place the units in an accessible place which could be reliably replicated for each horse and was quick and easy to attach and remove. Similar placements have been used in racehorse stride analysis, with the accelerometer attached to the saddle cloth on one side of the horse (Morrice-West *et al.*, 2020; Pfau *et al.*, 2009). The acceleration and displacement values of horse and jockey obtained in Chapters 6 and 7 were similar to those previously reported in the literature (Horan *et al.*, 2021; Pfau *et al.*, 2009; Walker *et al.*, 2016), so due to their consistent placement and comparability, the results were deemed valid.

To the author's knowledge, the present study is unique in being the first study of its kind to use the novel method of EMG integrated clothing to measure muscle activity of jockeys in training and competitive rides. Unlike other sports, riding a horse limits the accessibility to analyse the important and active muscles in the lower body of the jockey, due to the large surface area of the lower body in contact with the horse (in slower gaits for jockeys). The use of EMG integrated clothing enabled muscle groups in the lower body and legs of the jockey to be investigated with minimum interference to the jockey. The elasticised clothing was designed for a snug fit and visually, there appeared to be very good skin contact especially with the stretched electrodes over the lower back area, the *quadriceps* and *hamstrings*. The clothing was worn with braces to minimise textile movement and increase skin contact with electrodes over the upper body. However, the low value obtained for gluteal EMG in the studies described in Chapters 6 - 7 may have been affected by underwear worn by the jockeys meaning that the electrodes may not have picked up EMG signals from the *gluteal* group. However, as all jockeys were given the same instructions on donning the clothing, the problem was consistent between all jockeys. Muscle activity was assessed relative to the muscle activity from all muscles investigated, rather than normalised as a percentage of maximum muscle activity or frequency bands as has been previously reported in the literature (Terada, 2000; Terada *et al.*, 2004). This enabled gross comparison between muscle groups characterising the riding position in training, trials and races, rather than specific analysis of each muscular group. Further investigation to synchronise EMG data with kinematic and time-motion analyses may give further insight into the specificity between muscle recruitment and locomotion (Hug, 2011).

The use of EMG integrated clothing rather than precisely positioned electrodes as are traditionally used, does create the potential for the electrodes to move on the skin, creating a low frequency artefact and possible cross-talk from other muscles if the electrodes weren't stable in position (De Luca *et al.*, 2010; Hug, 2011). The 'textile' EMG recorded signals from large muscle groups, rather than individual muscles, thus the generalised signal from several muscles in a group encompassed cross-talk from unrelated muscle groups to some extent. Indeed, 'textile' EMG measurement in other applications have been shown to be comparable to traditional surface electrode EMG measurement during dynamic movements (Colyer *et al.*, 2018; Kraus, 2016). Nevertheless, it may have suffered from the usual difficulties associated with the EMG measurement. Notwithstanding these limitations, the discriminability of the data were consistent in the studies between different jockeys, making EMG integrated textile clothing a novel tool for use in the field, since it is almost impossible to envisage that intramuscular needle electrodes or specifically placed surface electrodes could ethically or practically be used to gather data of this nature. Future studies may be able to mitigate these limitations to a greater extent than was possible with the equipment available at the time of this study, and suggestions for potential future research avenues are described in the following section.

8.4 Recommendations for future studies

This thesis has described an association between competition (race) specific fitness and fall risk, performance, success and career longevity of jockeys. The majority of jockeys do not achieve sufficient race-level exercise. The differences in physiological demand, muscular activity profile and posture between race rides and training rides described in the thesis could be used to provide guidelines for practitioners to develop physical training protocols to improve race level fitness in apprentice jockeys.

Some specific ideas for further study are:

- Jockey head oscillation

  Movement of the jockeys' head was shown to differ between track- trial- and race-rides, particularly in the vertical plane (Chapters 6 - 7). Vertical head oscillation was lowest in race riding jockeys, who were all professional jockeys, as opposed to the mainly apprentice jockeys assessed in trial riding. As jockeys control the extent of damping of horse movement through synchronous muscle activity, those jockeys who are most successful at minimising their head movement likely have greater optimisation and hence better performance for both them and the horse. As such, measurement of jockey head movement may be a valuable assessment criterion of jockey performance, though further investigation into the relationship of head movement and jockey performance or experience variables may be required.

- Optimal training load

  It appears that higher numbers of race rides not only increase the chance of success, but the higher frequency of race riding may increase "competition fitness" and reduce the risk of injury. Finding and modelling this optimal training load in jockeys would benefit both professional jockeys to be able to adjust their competition loads, and for apprentice jockeys to determine the amount of training required to achieve optimum biological performance.

- Optimal number of jockeys

  The data presented in this thesis could be used to determine the optimal number of jockeys required by the industry to maintain the current level of Thoroughbred racing in New Zealand (or other jurisdictions). Limiting the numbers of apprentice jockeys to maintain an optimum number of working jockeys, though stricter selection criteria, may allow more intensive investment into the training and education of new apprentices and relieve competitive pressure to obtain rides on all professional jockeys.

- Kinematic analysis of EMG

  Further investigation to synchronise the EMG data of a jockey riding at canter and gallop with kinematic and time-motion analyses may give additional insight into the specificity between muscle recruitment and locomotion.

- Energy Expenditure

  Whilst HR is a common means of monitoring physical activity intensity, it cannot measure metabolic rate and thus physical work requirement. Measuring the energy expenditure (as an indication of aerobic demands) and power output (as a measure of anaerobic demands) of jockeys and horses to determine optimal training loads as has been done in other sports (cycling, rowing, running, kayaking) could be an interesting future avenue for study. This could be done using EMG data, following the methods of Tikkanen *et al.* (2014).

- Gender specificity

  Differences in phenotype and body composition between male and female jockeys may provide different physiological challenges when riding and when fasting to meet weight requirements and hence vary the onset of fatigue with cumulative effort. Additionally, male riders have been reported to have a biomechanical advantage when riding in the English style over female riders. Investigating differences in physiological demand and riding style between the genders may be an interesting future avenue for study.

- Other equestrian disciplines.

  The methodologies and insights assembled in this thesis could be further applied to explore and enhance rider performance in other equestrian disciplines such as show jumping, eventing and polo.

The final step in this research should be to create an off-horse jockey specific physical exercise training programme for apprentice jockeys, and then to assess the effects of implementing it on their physical fitness and riding position and ultimately their risk of injury and racing and career success. If jockeys' were able to shorten the latency in development of their race-specific physical conditioning without the pressure of obtaining race rides, this may have a significant positive impact on both horse and jockey welfare.

Industry modification to promote the social context of valuing the physical well-being of jockeys as elite athletes in all industry participants, in combination with early introduction of jockey specific training in a structured framework, may be a key component to the successful introduction of future jockey exercise programmes. Presentation of clear guidelines of the fitness levels associated with better riding performance could be presented to jockeys at the beginning of the apprenticeship programme. These guidelines could be accompanied with further education on the direct integration between off-horse exercise and race performance, as well as highlighting the benefits between consistent targeted sport specific exercise and weight management.

Although race riding is a heavily performance-oriented sport, use of exercise testing to select, assess progress and develop training programmes is not prevalent in the racing industry. Determining appropriate, informative, and accessible methods for physical fitness testing of jockeys and developing a physical fitness profile for jockeys would help to provide clear guidelines to structure a jockey fitness training programme. The assessment of a jockeys' physical characteristics may provide coaches and athletes with a reference physique and physical fitness profile that may aid in the development of physical fitness training programmes to optimise jockey and horse performance and health.

Centralising apprentice jockey training, providing access to suitable exercise and testing equipment (such as a racing simulator) to assess and practice riding position and fitness would allow both validation of the testing procedures used in this thesis, as well as providing clear guidelines to assess jockey fitness and skill before riding in a race. If apprentice jockeys in New Zealand were required to attend a block course of 8 weeks intensive training before dispersing to work for individual trainers, it would allow education and athlete lifestyle management practices to be instilled in the young jockeys. Combined with continued support from NZTR and the apprentice academy throughout the 4 years of the apprenticeship, this approach may improve the safety, performance and welfare of jockeys in New Zealand.

8.5 Thesis summary

Successful training interventions require knowledge of the physiological demands and performance characteristics of the specific sport. This thesis has shown that jockey inexperience and race-day fatigue are associated with an increased risk of jockey falls and thus jockey workload is an important avenue to investigate to improve jockey safety. Jockeys with higher competition specific workloads have lower injury risk, and greater competitive success, as well as longer, safer and more successful careers. Indeed, these jockeys experience a level of race-specific exercise which is lacking in jockeys with lower workloads (the majority of jockeys), who have poor career retention within the industry. Jockeys use riding (track-work, trials and races) as the primary way to achieve race fitness. However, the physiological demands of riding daily track-work are low, with no evidence of fatigue, and jockeys use both their legs and arms as stabilisers to damp horse motion. Trials act as a segue to race riding, with jockeys experiencing moderate to high intensity effort during a trial, but again using both their legs and (increasingly) arms to dampen horse oscillation. Jockeys riding races exercise at near maximal physiological potential, using only their legs to dampen horse oscillation in a lower crouched posture than that adopted by jockeys in track-work and trials, with their COM shifted anteriorly. Therefore, the competition (race) level performance demands of the jockey are not only higher than training level demands, but jockeys assume a different riding posture. Achieving race specific fitness in readiness for competition is important for jockey safety, performance, and career longevity and it appears insufficient to only ride training rides to gain race riding fitness. Therefore, future physical training guidelines should aim to specifically target the physiological demands of race riding which are not exercised through regular training rides.

By improving the conditioning of jockeys, it is hypothesised that the chance of errors can be reduced and the opportunity for jockeys to positively influence horses in race situations will increase. In the long term, this should enhance the jockey's ability to safely and optimally prepare for race riding, reducing the incidence of race day accidents and enhancing both horse and jockey welfare. If instigated early in a jockey's career, it would likely also improve the retention of quality jockeys within the industry. Therefore, there is a need for a clearly defined industry pathway that establishes and develops jockey race fitness and provides ample training opportunities for jockeys. The data presented in this thesis may be invaluable to the Thoroughbred racing industry (and potentially the wider equestrian community) as a starting point on which to develop strategies and policies to increase jockeys' fitness and ridden position on the horse thereby minimising the risk of racing injury, increasing jockey performance and career longevity.

8.6 Conclusions

In conclusion, this thesis has shown that:

- Chapter Two – Risk factors for jockey falls

Jockeys had a higher incidence rate (IR) of falls in flat than jumps races. Jockey inexperience and fatigue were associated with an increased risk of jockey falls during competitive racing.

- Chapter Three – Jockey external workload

  Most jockeys had low competitive racing workloads. Jockeys with higher competitive workloads have lower injury risk and greater race success.

- Chapter Four – Jockey career length

  Most jockeys have short (< 2 years) careers. Jockeys with higher competitive workloads have longer, safter and more successful careers.

- Chapter Five – Physical activities of jockeys

  Jockeys used riding training as their main form of fitness. A small proportion of elite jockeys experienced a higher level of race-specific exercise than most jockeys.

- Chapter Six – Physiological demands of track-work jockeys

  Riding track-work requires low physiological demand, with legs and arms working to dampen horse movement and stabilise the jockeys head movement.

- Chapter Seven – Physiological demands of trial and race jockeys

  Trial riding requires moderate to high physiological demand. Race riding requires near-maximal physiological demand. Race jockeys adopt a lower crouched posture than those riding in trials, with less vertical head oscillation and greater *hamstring* activation.

Riding training does not approximate race-specific physiological demands. There is a need for race-specific jockey training with clearly defined athletic milestones based on race-riding characteristics. Achieving race specific fitness in readiness for competition is important for jockey safety, performance, and career longevity.

The findings of the present thesis provide data for the Thoroughbred racing industry to assess jockey performance and increase jockeys' fitness and ridden position on the horse. In the long term, this should enhance the jockey's ability to safely and optimally prepare for race riding, reducing the incidence of race day accidents, increasing jockey career longevity and enhancing both horse and jockey welfare.

9 References

Abd-Elfattah, H. M., Abdelazeim, F. H., & Elshennawy, S. (2015). Physical and cognitive consequences of fatigue: A review. *Journal of Advanced Research,* 6(3): 351-358. doi:10.1016/j.jare.2015.01.011

Aegerter, A. M., Latif, S. N., Weishaupt, M. A., Gubler, B. E., Rast, F. M., Klose, A., Pauli, C. A., Meichtry, A., & Bauer, C. M. (2020). An investigation into the association of the physical fitness of equestrians and their riding performance: a cross-sectional study. *Comparative Exercise Physiology,* 16(2): 137-145. doi:10.3920/cep190052

Bailey, C. J., Rose, R. J., Reid, S. W., & Hodgson, D. R. (1997). Wastage in the Australian Thoroughbred racing industry: a survey of Sydney trainers. *Australian Veterinary Journal,* 75(1): 64-66.

Balyi, I., & Hamilton, A. (2004). *Long term athlete development: Trainability in childhood and adolescence. Windows of opportunity, optimal trainability.* Victoria, BC: National Coaching Institute British Columbia & Advanced Training and Performance Ltd.

Barrey, E., & Galloux, P. (1997). Analysis of the equine jumping technique by accelerometry. *Equine Veterinary Journal (Suppl 23)*: 45-49.

Baxter, J., Hobbs, S. J., Alexander, J., George, L. S., Sinclair, J., Chohan, A., & Clayton, H. M. (2022). Rider skill affects time and frequency domain postural variables when performing shoulder-in. *Journal of Equine Veterinary Science,* 109: 103805. doi:10.1016/j.jevs.2021.103805

Beaudouin, F., Aus der Funten, K., Tross, T., Reinsberger, C., & Meyer, T. (2019). Head injuries in professional male football (soccer) over 13 years: 29% lower incidence rates after a rule change (red card). *British Journal of Sports Medicine,* 53(15): 948-952. doi:10.1136/bjsports-2016-097217

Bennet, E. D., Cameron-Whytock, H., & Parkin, T. D. H. (2021). Federation Equestre Internationale eventing: Risk factors for horse falls and unseated riders during the cross-country phase (2008-2018). *Equine Veterinary Journal*. doi:10.1111/evj.13522

Bolwell, C. F., Rogers, C. W., & Gee, E. K. (2014). Descriptive epidemiology of race-day jockey falls and injuries in New Zealand. *Comparative Exercise Physiology,* 10(1): 49-55. doi:10.3920/cep13036

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science,* 56(1): 77- 81. doi:10.1071/an13442

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2017). Commercial equine production in New Zealand. 3. The racing and sport industries. *Animal Production Science*: A-K. doi:10.1071/an16753

Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and methodology of training* (5th ed.). Champaigne, IL, USA: Human Kinetics.

Borg, G. A. V. (1982). Symposium: Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise,* 14: 377-381.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sport Physiology and Performance,* 12(Suppl 2): S2161-S2170. doi:10.1123/IJSPP.2017-0208

Bye, T. L., & Martin, R. (2022). Static postural differences between male and female equestrian riders on a riding simulator. *Comparative Exercise Physiology,* 18(1): 1-8. doi:10.3920/cep210003

Colyer, S. L., & McGuigan, P. M. (2018). Textile electrodes embedded in clothing: A practical alternative to traditional surface electromyography when assessing muscle excitation during functional movements. *Journal of Sports Science and Medicine,* 17: 101-109.

Cullen, S. J., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. (2015). Physiological demands of flat horse racing jockeys. *Journal of Strength and Conditioning Research,* 29(11): 3060-3066.

Davies, M., Jackson, K. A., Mackinnon, A. L., Turner, A., Kuznik, K., Hill, J., Newton, J. L., & Sanchez Santos, M. (2021). Epidemiology of race day injury in young professional jockeys in Great Britain from 2007 to 2018: a retrospective cohort study. *BMJ Open,* 11(8): e044075. doi:10.1136/bmjopen-2020-044075

De Luca, C. J., Gilmore, L. D., Kuznetsov, M., & Roy, S. H. (2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *Journal of Biomechanics,* 43(8): 1573-1579. doi:10.1016/j.jbiomech.2010.01.027

Demarie, S., Galvani, C., Donatucci, B., & Gianfelici, A. (2022). A pilot study on Italian eventing prospective Olympic horse riders physiological, anthropometrical, functional and asymmetry assessment. *Central European Journal of Sport Sciences and Medicine,* 37(1): 77–88. doi:10.18276/cej.2022.1-07

Douglas, J. (2017). *Physiological demands of eventing and performance related fitness in female horse riders.* (Doctor of Philosophy), University of Worcester, UK.

Edwards, S. (1993). High performance training and racing. In *The Heart Rate Monitor Book* (8th Edn ed., pp. 113–123). Sacramento, CA: Feet Fleet Press.

Egenvall, A., Clayton, H., Engell, M. T., Roepstorff, C., Engstrom, H., & Bystrom, A. (2022). Roll and pitch of the rider's pelvis during horseback riding at walk on a circle. *Journal of Equine Veterinary Science,* 109: 103798. doi:10.1016/j.jevs.2021.103798

Gabbett, T. J. (2020a). Debunking the myths about training load, injury and performance: empirical evidence, hot topics and recommendations for practitioners. *British Journal of Sports Medicine,* 54(1).

Gabbett, T. J. (2020b). The training-performance puzzle: How can the past inform future training directions? *Journal of Athletic Training,* 55(9): 874-884. doi:10.4085/1062/6050.422.19

Giusti Gestri, L. (2021). Is it still worth challenging the status quo? A design process article with an example application to Australian jockey's safety vests. *Ergonomics in Design: The Quarterly of Human Factors Applications*. doi:10.1177/1064804620986642

Gonzalez, M. E., & Šarabon, N. (2021). Shock attenuation and electromyographic activity of advanced and novice equestrian riders' trunk. *Applied Sciences,* 11(5). doi:10.3390/app11052304

Gulbin, J., Weissensteiner, J., Oldenziel, K., & Gagne, F. (2013a). Patterns of performance development in elite athletes. *European Journal of Sport Science,* 13(6): 605-614. doi:10.1080/17461391.2012.756542

Gulbin, J. P., Croser, M. J., Morley, E. J., & Weissensteiner, J. R. (2013b). An integrated framework for the optimisation of sport and athlete development: a practitioner approach. *Journal of Sports Sciences,* 31(12): 1319-1331. doi:10.1080/02640414.2013.781661

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine,* 44 (Suppl 2): S139-147. doi:10.1007/s40279-014-0253-z

Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. (2011). Predictors of race-day jockey falls in jumps racing in Australia. *Accident Analysis and Prevention,* 43(3): 840-847. doi:10.1016/j.aap.2010.11.003

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L., & Fell, J. (2010). Predictors of race-day jockey falls in flat racing in Australia. *Occupational and Environmental Medicine,* 67(10): 693-698. doi:10.1136/oem.2009.050567

Hitchens, P. L., Blizzard, C. L., Jones, G., Day, L. M., & Fell, J. (2012). The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention,* 18(6): 385-391. doi:10.1136/injuryprev-2011-040255

Hodgson, D. R., McKeever, K. H., & McGowan, C. M. (Eds.). (2014). *The athletic horse : principles and practice of equine sports medicine* (2nd ed.). St. Louis: Saunders/Elsevier.

Horan, K., Kourdache, K., Coburn, J., Day, P. S., Carnall, H., Harborne, D., Brinkley, L., Hammond, L., Millard, S. W., Lancaster, B., & Pfau, T. (2021). The effect of horseshoes and surfaces on horse and rider centre of mass displacements at gallop. *Plos One,* (in press).

Hug, F. (2011). Can muscle coordination be precisely studied by surface electromyography? *Journal of Electromyography and Kinesiology,* 21(1): 1-12. doi:10.1016/j.jelekin.2010.08.009

IER. (2018). *Size and Scope of the New Zealand Racing Industry* New Zealand Racing Board: https://www.nzrb.co.nz/sites/default/files/documents/NZ%20Racing%20Size%20and%20Scope%202018%20Full%20Report.pdf

International Federation of Horse Racing Authorities. (2019). *IFHRA Annual Report 2019*. Boulogne, France:

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicince and Science in Sports,* 20 (Suppl 2): 95-102. doi:10.1111/j.1600-0838.2010.01192.x

Kiely, M., Warrington, G., McGoldrick, A., & Cullen, S. (2020). Physical preparation strategies of professional jockeys. *Journal of Strength and Conditioning Research*. doi:10.1519/jsc.0000000000003514

Kiely, M. A., Warrington, G. D., 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. doi:10.23736/S0022-4707.18.08196-3

King, L., Cullen, S. J., McArdle, J., McGoldrick, A., Pugh, J., Warrington, G., & Losty, C. (2021). Stressors experienced by professional jockeys. *The Sport Psychologist,* 35(2): 142-154. doi:10.1123/tsp.2020-0128

Kraus, K. (2016). *Reliability of textile electromyography parameters.* Universität der Bundeswehr München,

Leger, L. A., Mercier, D., Gadouryl, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences,* 6: 93-101.

Legg, K. A., Breheny, M., Gee, E. K., & Rogers, C. W. (2019). Responding to risk: Regulation or prohibition? New Zealand media reporting of Thoroughbred jumps racing 2016–2018. *Animals,* 9(5): 276. doi:10.3390/ani9050276

Longo, U. G., Loppini, M., Berton, A., Marinozzi, A., Maffulli, N., & Denaro, V. (2012). The FIFA 11+ program is effective in preventing injuries in elite male basketball players: a cluster randomized controlled trial. *The American Journal of Sports Medicine,* 40(5): 996-1005. doi:10.1177/0363546512438761

Losty, C., Warrington, G., McGoldrick, A., Murphy, C., Burrows, E., & Cullen, S. (2019). Mental health and wellbeing of jockeys. *Journal of Human Sport & Exercise,* 14(1): 147-157.

McManus, P., Graham, R., & Ruse, K. (2014). The construction of human-animal relations: National Jumps Day 2013 at Te Rapa, Hamilton, New Zealand. *New Zealand Geographer,* 70(3): 190-200. doi:10.1111/nzg.12068

Mizobe, F., Takahashi, Y., & Kusano, K. (2021). Risk factors for jockey falls in Japanese Thoroughbred flat racing. *Journal of Equine Veterinary Science*. doi:10.1016/j.jevs.2021.103749

Moore, R. D., Romine, M. W., O'Connor P, J., & Tomporowski, P. D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Sciences,* 30(9): 841-850. doi:10.1080/02640414.2012.675083

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., Wong, A. S. M., & Whitton, R. C. (2020). Variation in GPS and accelerometer recorded velocity and stride parameters of galloping Thoroughbred horses. *Equine Veterinary Journal*. doi:10.1111/evj.13370

New Zealand Qualifications Authority. (2018). *National Certificate in Equine (Level 4) with strands in Sporthorse Stable Attendant, Harness Racing, Sporthorse Competitor, Jockey and Advanced Track Rider*. Primary Industry Training Organisation: https://www.nzqa.govt.nz/nqfdocs/quals/pdf/0216.pdf

New Zealand Thoroughbred Racing. (2019a). *Handicapping guide*. Wellington, New Zealand: https://loveracing.nz/OnHorseFiles/LoveRacing/Articles/2018/2019%20Handicapping%20Policy%20(Effective%20from%201%20August%202019).pdf

New Zealand Thoroughbred Racing. (2019b). *New Zealand apprentice jockey programme*. New Zealand Trainers Association:

New Zealand Thoroughbred Racing. (2019c). *New Zealand Thoroughbred Racing Incorporated amended rules of racing* https://loveracing.nz/OnHorseFiles/Downloads/RULES%20OF%20RACING%20(effective%20from%201%20April%202019).pdf

O'Connor, S., Warrington, G., Mb, A. M., & Cullen, S. (2018). A 9-year epidemiologic study (2007-2015) on race-day jockey fall and injury incidence in amateur Irish horse racing. *Journal of Athletic Training,* 53(10): 950-955. doi:10.4085/1062-6050-339-17

O’Connor, S., Warrington, G., O’Brien, S., McDermott, E., McGoldrick, A., Pugh, J., & Cullen, S. (2020). Injuries outside of horseracing: is it time to focus on injury prevention of jockeys outside of races? *The Physician and Sportsmedicine,* 49(1): 45-50. doi:10.1080/00913847.2020.1760693

Padilla, S., Mujika, I., Orbananos, J., Santisteban, J., Angulo, F., & Goiriena, J. (2001). Exercise intensity and load during mass-startstage races in professional road cycling. *Medicine and Science in Sports and Exercise,* 33: 796–802.

Parkin, T. D. H., Clegg, P. D., French, N. P., Proudman, C. J., Riggs, C. M., Singer, E. R., Webbon, P. M., & Morgan, K. L. (2004). Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal,* 36 (6): 521-526.

Perkins, N. R., Reid, S. W. J., & Morris, R. S. (2005). Profiling the New Zealand Thoroughbred racing industry. 1. Training, racing and general health patterns. *New Zealand Veterinary Journal,* 53(1): 59-68.

Peterson, M. L., Wayne McIlwraith, C., & Reiser, R. F. (2008). Development of a system for the in-situ characterisation of Thoroughbred horse racing track surfaces. *Biosystems Engineering,* 101(2): 260-269. doi:10.1016/j.biosystemseng.2008.07.007

Pfau, T., Spence, A., Starke, S., Ferrari, M., & Wilson, A. (2009). Modern riding style improves horse racing times. *Science,* 325(5938): 289. doi:10.1126/science.1174605

Rogers, C. W., Bolwell, C. F., Gee, E. K., Peterson, M. L., & McIlwraith, C. W. (2014). Profile and surface conditions of New Zealand Thoroughbred racetracks. *Journal of Equine Veterinary Science,* 34(9): 1105-1109. doi:10.1016/j.jevs.2014.06.017

Rosanowski, S. M., Rogers, C. W., Bolwell, C. F., & Cogger, N. (2015). The movement pattern of horses around race meetings in New Zealand. *Animal Production Science,* 55(8): 1075-1080. doi:10.1071/an13345

Ryan, K., & Brodine, J. (2021). Weight-making practices among jockeys: An update and review of the emergent scientific literature. *Open Access Journal of Sports Medicine,* 12: 87-98. doi:10.2147/oajsm.S235143

Speed, H., Seedsman, T., Morris, T., and Sullivan, R. (2001). *The welfare of retired jockeys.* Melbourne: Victoria University of Technology, Centre for Rehabilitation, Exercise and Sports Science.

Stodden, D., Langendorfer, S., & Roberton, M. A. (2009). The association between motor skill competence and physical fitness in young adults. *Research Quarterly for Exercise and Sport,* 80(2): 223-229. doi:10.1080/02701367.2009.10599556

Terada, K. (2000). Comparison of head movement and EMG activity of muscles between advanced and novice horseback riders at different gaits. *Journal of Equine Veterinary Science,* 11(4): 83-90. doi:10.1294/jes.11.83

Terada, K., Mullineaux, D. R., Lanovaz, J., Kato, K., & Clayton, H. M. (2004). Electromyographic activity of the rider's muscles at trot. *Equine and Comparative Exercise Physiology,* 1(3): 193-198. doi:10.1079/ECEP200420

Tikkanen, O., Karkkainen, S., Haakana, P., Kallinen, M., Pullinen, T., & Finni, T. (2014). EMG, heart rate, and accelerometer as estimators of energy expenditure in locomotion. *Medicine and Science in Sports and Exercise,* 46(9): 1831-1839. doi:10.1249/MSS.0000000000000298

Turner, M., McCrory, P., & Halley, W. (2002). Injuries in professional horse racing in Great Britain and the Republic of Ireland during 1992-2000. *British Journal of Sports Medicine,* 36: 403-409.

Vriend, I., Gouttebarge, V., Finch, C. F., van Mechelen, W., & Verhagen, E. (2017). Intervention strategies used in sport injury prevention studies: A systematic review identifying studies applying the haddon matrix. *Sports Medicine,* 47(10): 2027-2043. doi:10.1007/s40279-017-0718-y

Walker, A. M., Applegate, C., Pfau, T., Sparkes, E. L., Wilson, A. M., & Witte, T. H. (2016). The kinematics and kinetics of riding a racehorse: A quantitative comparison of a training simulator and real horses. *Journal of Biomechanics,* 49(14): 3368-3374. doi:10.1016/j.jbiomech.2016.08.031

Williams, S., Trewartha, G., Kemp, S. P. T., Brooks, J. H. M., Fuller, C. W., Taylor, A. E., Cross, M. J., Shaddick, G., & Stokes, K. A. (2017). How much rugby is too much? A seven-season prospective cohort study of match exposure and injury risk in professional rugby union players. *Sports Medicine,* 47(11): 2395-2402. doi:10.1007/s40279-017-0721-3

Wilson, G., Hawken, M. B., Poole, I., Sparks, A., Bennett, S., Drust, B., Morton, J., & Close, G. L. (2014). Rapid weight-loss impairs simulated riding performance and strength in jockeys: implications for making-weight. *Journal of Sports Sciences,* 32(4): 383-391. doi:10.1080/02640414.2013.825732

Appendices

Appendix A Univariable table of risk factors for jockey falls in flat races 220

Appendix B Univariable table of risk factors for jockey falls in hurdle races 222

Appendix C Univariable table of risk factors for jockey falls in steeplechase races 224

Appendix D Jockey workload diary 226

Appendix E Horse Pull/Contact and Borg RPE rating scale 239

Appendix F Mean linear accelerations and displacements of horse and jockey during trials and races 241

Appendix G Ethical approval documentation 242

Appendix H Participant information sheet 244

Appendix I Participant consent form 249

Appendix J Statements of contributions to research 250

Appendix A

Univariable table of risk factors for jockey falls in flat races

Table A.1 Univariable Poisson regression of association between jockey falls in flat races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, flat rating (of horse), number of starters, jockey gender and age, maximum number of race day rides and the number of races previously ridden by the jockey on a race day.

Variable	Category	Jockey Falls (%)	Starts	IRR (95% CI)		P	P (Wald)
Season	Autumn	13 (0.01%)	102798	1.00	-	-	<0.001
	Winter	73 (0.09%)	110586	0.92	(0.68-1.23)	0.55	
	Spring	130 (0.12%)	115009	1.17	(0.91-1.52)	0.23	
	Summer	185 (0.16%)	79555	1.61	(1.26-2.04)	<0.001	
Race Distance (m)	785 - 1200	26 (0.13%)	19434	1.09	(0.73-1.64)	0.67	0.8
	1200 - 1600	236 (0.12%)	201457	0.96	(0.80-1.15)	0.65	
	> 1600	229 (0.12%)	187057	1.00	-	-	
Track Condition	Fast	8 (0.13%)	5936	1.06	(0.52-2.16)	0.87	0.003
	Good	198 (0.14%)	138898	1.12	(0.91-1.39)	0.29	
	Dead	150 (0.13%)	117546	1.00	-	-	
	Slow	62 (0.09%)	72546	0.67	(0.50-0.90)	0.01	
	Heavy	73 (0.10%)	73022	0.78	(0.59-1.03)	0.08	
Horse Gender	Female	231 (0.12%)	189497	1.00	-	-	0.8
	Male	260 (0.12%)	218451	0.97	(0.82-1.16)	0.77	
Horse Age	2-3	149 (0.14%)	102992	1.00	-	-	0.02
	4	148 (0.12%)	120277	0.83	(0.66-1.05)	0.12	
	5	106 (0.12%)	91739	0.77	(0.60-0.99)	0.05	
	6-13	88 (0.09%)	92940	0.63	(0.48-0.82)	0.001	
Experience	Apprentice	138 (0.17%)	80509	1.00	-	-	<0.001
	Jockey	353 (0.11%)	327439	0.64	(0.52-0.79)	<0.001	
Carried Weight (kg)	< 54	90 (0.17%)	52328	1.00	-	-	0.0003
	54 - 56	177 (0.13%)	135295	0.78	(0.61-1.01)	0.06	
	56 - 58	164 (0.10%)	159545	0.62	(0.48-0.81)	<0.001	
	58+	60 (0.10%)	60780	0.59	(0.42-0.83)	0.002	
Flat Rating	Maiden <55	201 (0.15%)	132257	1.00	-	-	<0.001
	Rating 65	122 (0.12%)	102693	0.78	(0.62-0.98)	0.03	
	Rating 75	87 (0.09%)	98900	0.58	(0.45-0.75)	<0.001	
	Rating 85	50 (0.12%)	41197	0.80	(0.59-1.09)	0.16	
	Open >85	31 (0.09%)	32895	0.62	(0.43-0.91)	0.02	
Number of starters	< 14	10 (0.08%)	11784	1.00	-	-	0.2
	14 - 16	68 (0.13%)	53503	1.50	(0.81-3.10)	0.23	
	16 - 18	21 (0.09%)	24373	1.02	(0.49-2.25)	0.97	
Jockey Gender	Female	148 (0.11%)	129296	1.00	-	-	0.5
	Male	340 (0.12%)	278094	1.07	(0.88-1.30)	0.50	

Jockey Age (years)	15 - 26	150 (0.12%)	121496	1.00	-	-	0.08
	27 - 31	144 (0.14%)	103945	1.17	(0.90-1.51)	0.23	
	32 - 39	103 (0.12%)	86561	0.97	(0.73-1.29)	0.82	
	40 +	94 (0.10%)	95586	0.77	(0.57-1.05)	0.10	
Max number of race day rides	1	81 (0.37%)	21934	1.00	-	-	<0.001
	2	84 (0.23%)	36409	0.62	(0.46-0.85)	0.003	
	3	71 (0.15%)	45987	0.42	(0.30-0.57)	<0.001	
	4	54 (0.09%)	56968	0.26	(0.18-0.36)	<0.001	
	5	60 (0.10%)	61992	0.26	(0.19-0.37)	<0.001	
	6	55 (0.09%)	60891	0.24	(0.17-0.34)	<0.001	
	7	47 (0.09%)	54013	0.24	(0.16-0.34)	<0.001	
	8	23 (0.06%)	38955	0.16	(0.10-0.25)	<0.001	
	9+	16 (0.05%)	30799	0.14	(0.08-0.23)	<0.001	
Ride number on race day	1	155 (0.14%)	107777	1.00	-	-	0.15
	2	107 (0.12%)	86229	0.86	(0.67-1.10)	0.24	
	3	78 (0.11%)	68065	0.80	(0.60-1.04)	0.10	
	4	49 (0.09%)	52747	0.65	(0.46-0.88)	0.01	
	5	40 (0.10%)	38517	0.72	(0.50-1.01)	0.07	
	6	30 (0.11%)	26096	0.80	(0.53-1.16)	0.26	
	7+	32 (0.11%)	28517	0.78	(0.52-1.13)	0.20	

Appendix B
Univariable table of risk factors for jockey falls in hurdle races

Table B.1 Univariable Poisson regression of association between jockey falls in hurdle races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, hurdles rating, number of starters, jockey gender and age, maximum number of race day rides and the number of races ridden previously by the jockey on a race day.

Variable	Category	Jockey Falls (%)	Starts	IRR (95% CI)	P	P (Wald)
Season	Autumn	75 (4.8%)	1548	1.00 -	-	0.1
	Winter	266 (5.1%)	5172	1.06 (0.82-1.38)	0.63	
	Spring	106 (6.3%)	1675	1.32 (0.98-1.77)	0.07	
Race Distance (m)	2400 - 2800	88 (4.2%)	2102	0.71 (0.54-0.93)	0.01	0.03
	2800 - 3100	219 (5.5%)	3955	0.95 (0.77-1.18)	0.64	
	3100 - 4400	137 (5.9%)	2338	1.00 -	-	
Track Condition	Fast	1 (4.2%)	24	0.68 (0.10-4.92)	0.71	0.04
	Good	22 (6.3%)	351	1.03 (0.64-1.64)	0.90	
	Dead	88 (6.1%)	1441	1.00 -	-	
	Slow	141 (6.0%)	2345	1.01 (0.78-1.32)	0.93	
	Heavy	192 (4.5%)	4234	0.75 (0.58-0.96)	0.02	
Horse Gender	Female	49 (6.1%)	801	1.00 -	-	0.2
	Male	395 (5.2%)	7594	0.8 (0.60-1.09)	0.2	
Horse Age	3 - 6	189 (5.3%)	3584	1.00 -	-	0.7
	7	102 (5.4%)	1901	1.02 (0.80-1.30)	0.85	
	8	86 (5.7%)	1507	1.10 (0.85-1.42)	0.46	
	9+	67 (4.8%)	1403	0.90 (0.68-1.20)	0.48	
Experience	Apprentice	122 (5.4%)	2239	1.00 -	-	0.9
	Jockey	322 (5.2%)	6156	0.99 (0.79-1.23)	0.91	
Carried Weight (kg)	< 64	208 (6.2%)	3343	1.00 -	-	0.007
	64 - 66	118 (4.3%)	2713	0.69 (0.55-0.87)	0.002	
	66+	121 (5.2%)	2339	0.84 (0.66-1.05)	0.13	
Hurdles Rating	Maiden	192 (6.3%)	3064	1.00 -	-	0.02
	Rating 65	90 (4.5%)	1979	0.74 (0.58-0.95)	0.02	
	Rating 75	75 (4.6%)	1618	0.74 (0.57-0.97)	0.03	
	Rating 85	28 (3.9%)	727	0.61 (0.41-0.91)	0.01	
	Open	58 (5.8%)	993	0.93 (0.69-1.25)	0.64	
Number of starters	<12	4 (3.2%)	125	0 Inf	1.00	0.9
	12-14	45 (4.9%)	919	1.00 -	-	
	14-16	65 (4.6%)	1422	1.11 (0.71-1.74)	0.64	
Jockey Gender	Female	68 (4.8%)	1409	1.00 -	-	0.4
	Male	377 (5.4%)	6966	1.12 (0.87-1.46)	0.38	
	17 - 27	136 (5.0%)	2697	1.00 -	-	

Jockey Age	28 - 33	145 (5.8%)	2487	1.13	(0.86-1.47)	0.38	0.3
	34 - 35	70 (4.6%)	1530	0.87	(0.62-1.23)	0.44	
	35+	92 (5.7%)	1625	1.14	(0.84-1.53)	0.40	
Max number of race day rides	1	119 (8.4%)	1410	1.00	-	-	<0.001
	2	135 (5.4%)	2490	0.64	(0.50-0.82)	<0.001	
	3	94 (4.5%)	2104	0.53	(0.40-0.69)	<0.001	
	4+	99 (4.1%)	2391	0.49	(0.38-0.64)	<0.001	
Ride number on race day	1	297 (5.7%)	5245	1.00	-	-	0.2
	2	106 (4.7%)	2278	0.82	(0.66-1.02)	0.08	
	3+	44 (5.0%)	872	0.89	(0.64-1.21)	0.48	

Appendix C

Univariable table of risk factors for jockey falls in steeplechase races

Table C.1 Univariable Poisson regression of association between jockey falls in steeplechase races and predictor variables; season of the year, race distance (m), track condition, horse gender, horse age, jockey experience (apprentice or jockey), carried weight, hurdles rating, number of starters, jockey gender and age, maximum number of race day rides and the number of races ridden previously by the jockey on a race day.

Variable	Category	Jockey	Starts	IRR (95% CI)	P	P
Season	Autumn	103	861	1.00 -	-	0.1
	Winter	326 (9.5%)	3424	0.79 (0.64-0.99)	0.04	
	Spring	96 (9.9%)	968	0.83 (0.63-1.10)	0.19	
Race Distance (m)	3100 -	106 (9.2%)	1156	1.02 (0.79-1.33)	0.88	0.06
	4000 -	298	2717	1.24 (1.01-1.54)	0.04	
	4200 -	121 (8.8%)	1380	1.00 -	-	
Track Condition	Fast	0 (0.0%)	3	na -	-	0.06
	Good	15 (7.1%)	211	0.57 (0.32-0.95)	0.04	
	Dead	94 (12.6%)	749	1.00 -	-	
	Slow	132 (9.3%)	1416	0.74 (0.57-0.97)	0.03	
	Heavy	284 (9.9%)	2874	0.79 (0.63-1.00)	0.04	
Horse Gender	Female	43 (11.2%)	384	1.00 -	-	0.4
	Male	482 (9.9%)	4869	0.87 (0.64-1.19)	0.39	
Horse Age	4 - 7	233	2190	1.00 -	-	0.04
	8	118	1019	1.08 (0.86-1.35)	0.50	
	9	72 (8.1%)	886	0.75 (0.58-0.98)	0.04	
	10+	102 (8.8%)	1158	0.82 (0.65-1.03)	0.09	
Experience	Apprentice	156	1158	1.00 -	-	<0.001
	Jockey	369 (9.0%)	4095	0.70 (0.57-0.85)	<0.001	
Carried Weight (kg)	< 64	224	1991	1.00 -	-	0.05
	64 - 66	170 (9.8%)	1729	0.86 (0.70-1.06)	0.16	
	66+	131 (8.5%)	1533	0.75 (0.60-0.94)	0.01	
Steeples Rating	Maiden	201	1353	1.00 -	-	<0.001
	Rating 65	109 (8.4%)	1293	0.57 (0.45-0.73)	<0.001	
	Rating 75	82 (8.6%)	951	0.58 (0.45-0.76)	<0.001	
	Rating 85	49 (7.4%)	659	0.50 (0.37-0.69)	<0.001	
	Open	83 (8.4%)	989	0.59 (0.45-0.76)	<0.001	
Number of starters	< 13	26 (8.6%)	303	0.85 (0.53-1.37)	0.50	0.8
	13 - 15	51 (10.1%)	506	1.00 -	-	
	15 - 16	21 (8.8%)	238	0.88 (0.53-1.46)	0.61	
Jockey Gender	Female	91 (9.6%)	949	1.00 -	-	0.6
	Male	432	4297	0.93 (0.69-1.25)	0.61	
Jockey Age	17 - 28	191	1748	1.00 -	-	0.03
	29 - 33	159	1436	1.01 (0.79-1.30)	0.93	

	34 - 35	102 (9.5%)	1077	0.88	(0.65-1.19)	0.40	
	35+	68 (7.1%)	956	0.64	(0.47-0.87)	0.005	
Max number of race day rides	1	71 (14.2%)	500	1.00	-	-	0.004
	2	172	1671	0.72	(0.55-0.96)	0.02	
	3	119 (8.6%)	1385	0.61	(0.45-0.82)	<0.001	
	4+	163 (9.6%)	1697	0.68	(0.51-0.90)	0.01	
Ride number on race day	1	130	1176	1.00	-	-	0.3
	2	186	1847	0.91	(0.73-1.14)	0.41	
	3	209	1306	0.91	(0.72-1.17)	0.47	
	4+	77 (8.3%)	924	0.75	(0.57-1.00)	0.05	

Appendix D
Jockey workload diary

This diary was an online Qualtrics survey which jockeys accessed daily through a personalized link sent to them via email.

Survey Completion

0% 1

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Q1.1.
This daily diary is designed to gain a better understanding of your physical activities and experience in and outside of your work as a jockey or apprentice. This information will be used to help create a set of exercises specifically to help improve your riding fitness and ability.
After the introductory section, there are some short questions for you to fill in each day during a week. Your help in this project is greatly appreciated.

Q1.2. Age: How old are you?

Age (years)

→

Survey Completion

0% 1

Q1.3. Gender: Are you....?

- Male
- Female
- Other

Q1.4. How tall are you (cm)?

Height (cm)

Q1.5. What is your riding weight (kg)?

Weight (kg)

← →

Survey Completion

0% 1

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Q1.7. What is your shoe size?

NZ SIZE	UK SIZE	EU SIZE	US SIZE	Japan	FOOT LENGTH (MM)
4	2	35	4	21	212
5	3	36	5	22	220
6	4	37	6	23	229
7	5	38	7	24	237
8	6	39	8	25	246
9	7	40	9	26	254
10	8	41	10	27	262
11	9	42	11	28	270

Shoe size (NZ)

←

→

Survey Completion

0% 1

Q2.1. What type of licence do you currently hold?

- Track rider
- Apprentice
- Jockey
- Amateur
- Jumps

Q2.2. When did you obtain your current licence? (Choose a date from the calendar, or enter date in yyyy-mm-dd format in box below)

← September 2022 →

Su	Mo	Tu	We	Th	Fr	Sa
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	1
2	3	4	5	6	7	8

Q2.3. How many years have you been ....?

riding horses?

riding track work?

riding in races

Q2.4. If you rode horses BEFORE starting to work in the racing industry, what was your **MAIN** discipline?

Dressage

Show Jumping

Eventing

Hunting

Pleasure/trekking

Pony Club

Western

Other

←

→

Survey Completion

0% 1

Q3.1. In the last 12 months, how many falls (from a horse) have you had...?

during track work or training?

during a race?

during riding outside of work?

Q3.2. In the last 12 months, how many falls (from a horse) have resulted in injury requiring time off work?

during track work or training?

during a race?

during riding outside of work?

Q3.3. What do you think was the main cause for the majority of your falls from a horse?

- Rider tiredness
- Riding ability
- Rider inattention
- Other riders
- Horse behaviour
- Gear issue
- Weather
- Other

Survey Completion

0% 1

Q4.1. Please fill in this section for **MONDAY** only

Q4.2. What were your working hours today?

Morning start time	
Morning end time	
Afternoon start time	
Afternoon end time	

← →

Survey Completion

0% 1

Q4.3. Did you ride any horses at work today?

Yes

No

← →

Survey Completion

0% 1

Q4.4. How many horses did you ride today?

at track work?

at the races?

Q4.5. How long did you spend riding **each** horse during track work? (give most common time eg. twice around the track for a slow workout would be about 5 minutes)

- 0 - 5 minutes
- 6 - 10 minutes
- 11 - 15 minutes
- 16 - 20 minutes
- 21 - 25 minutes
- 26 - 30 minutes
- 30 + minutes

Q4.6. How many times around the track (or equivalent) did you ride each horse today? (give most common workout)

- Once round the track (1600 - 1800m)
- Twice round the track (3200 - 3600m)
- Three times round track (4800 - 5400m)
- Four times round track (6400 - 7200m)
- Other

Q4.7. What percentage of your time at work was spent..... (click bars to pull them to a percentage of your workday time)

Percentage of time at work

	0 10 20 30 40 50 60 70 80 90 100	
Mucking out		0
Riding trackwork		0
Sweeping/cleaning		0
Feeding/watering		0
Grooming horses		0
At races		0
Other (please describe)		0
Other (please describe)		0
Total:		**0**

Q4.8. Did you do any extra physical activity today? (eg. non-work riding, running, cycling, yoga, walking, netball, circuit training)

Yes

No

←

→

Q6.9. What other activities did you do today?

	0 - 0.5 hrs	0.5 - 1 hr	1 - 1.5 hr	1.5 - 2 hr	2 + hrs
Riding (non work)	○	○	○	○	○
Running	○	○	○	○	○
Cycling	○	○	○	○	○
Yoga/Pilates	○	○	○	○	○
Walking	○	○	○	○	○
Circuit training	○	○	○	○	○
Gym	○	○	○	○	○
Rowing machine	○	○	○	○	○
Swimming	○	○	○	○	○
Team Sports	○	○	○	○	○
Other (please describe)	○	○	○	○	○
Other (please describe)	○	○	○	○	○

Survey Completion

0% 1

Q5.1.

You rode 5 horses this week

You rode 18 km

You spent 25 mins in canter/gallop

Please **STOP** survey here.

An email will be sent to you tomorrow to continue survey from this point.

→

This final Block (Workload Diary – Monday) was repeated for each day of the week (until Sunday) when the jockeys were thanked for completing the survey and given their final riding tally for the week.

Survey Completion

0% 1

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Q17.1.

You rode 29 horses this week

You rode 97.2 km

You spent 195 mins in canter/gallop

Thank you for completing the workload diary for one week!

→

Survey Completion

0% 1

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Thank you for completing the equestrian riders workload questionairre!
This daily diary is designed to gain a better understanding of your physical activities and experience in and outside of your riding activities. This information will be used to help create a set of exercises specifically to help improve your riding fitness and ability.

Appendix E
Horse Pull/Contact and Borg RPE rating scale

Table E.1 Horse pull rating scale and Borg's rating of perceived exertion 10-point scale used with jockeys (n = 10) to score each ride of a morning's track-work. Adapted from (Borg, 1982)

Horse Pull/Contact	Scale	Borg RPE
Kick on	0	Nothing at all
Kick a bit	1	Very, very easy
*	2	Easy
No pull, no kick on	3	Moderate
*	4	Somewhat Hard
Pulls a bit	5	Hard
*	6	*
Keep a hold	7	Very Hard
*	8	*
Hold hard	9	*
Can't hold/stop	10	Maximal

Terminology:

Kick on	Horse needs encouragement to maintain its pace
No pull, No kick on	Horse is 'on the bridle' and travels at a consistent pace with a light rein contact and no encouragement
Pulls a bit	Horse requires rider to maintain a steady pressure on the reins otherwise it would increase speed
Keep a hold	Rider required to maintain a strong pressure bridge hold on the reins to prevent horse increasing speed
Hold hard	Rider required to maintain a maximum pressure bridge hold on the reins to prevent horse increasing speed
Can't hold/stop	Horse increases speed irrespective of rider

Appendix F
Mean linear accelerations and displacements of horse and jockey during trials and races

Supplementary Table 2. Mean (± SD) linear accelerations and displacements of horse (n = 32) and jockey's head during trials (n = 48) and races (n = 10).

Table F.1 Mean (± SD) linear accelerations and displacements of horse (n = 32) and jockey's head during trials (n = 48) and races (n = 10).

Variable	Descriptor	Vertical	Medial/lateral	Fore/Aft	Magnitude
Dominant frequency (Hz)	Trials Horse	2.3 ± 0.2	2.4 ± 0.1	2.3 ± 0.2	2.3 ± 0.4
	Trials Jockey	2.4 ± 0.1	2.2 ± 0.5	2.3 ± 0.2	2.3 ± 0.1
	Race Jockey	2.3 ± 0.1	2.1 ± 0.6	2.3 ± 0.1	2.3 ± 0.1
	ES (Trials)	0.2	0.7	0.0	0.3
	ES (Jockey)	0.7	0.3	0.1	0.0
Displacement (m)	Trials Horse	0.102 ± 0.023^{+}	0.078 ± 0.023^{+}	0.149 ± 0.04^{+}	0.114 ± 0.028^{+}
	Trials Jockey	0.067 ± 0.027	0.023 ± 0.007	0.037 ± 0.016	0.054 ± 0.021
	Race Jockey	0.055 ± 0.023*	0.028 ± 0.010*	0.056 ± 0.025*	0.056 ± 0.022
	ES (Trials)	2.0	4.6	5.2	3.4
	ES (Jockey)	0.7	0.8	1.3	0.1
Mean linear acceleration ($m \cdot s^{-2}$)	Trials Horse	45.3 ± 14.6^{+}	33.1 ± 13.8^{+}	53.7 ± 17.6^{+}	37.5 ± 8.4^{+}
	Trials Jockey	22.2 ± 8.0	8.2 ± 2.4	10.6 ± 3.4	16.1 ± 5.6
	Race Jockey	21.4 ± 9.0	9.3 ± 2.9*	13.9 ± 5.3*	15.8 ± 5.2
	ES (Trials)	2.8	3.6	4.8	4.2
	ES (Jockey)	0.1	0.6	1.1	0.1
Peak linear acceleration ($m \cdot s^{-2}$)	Trials Horse	74.5 ± 16.6^{+}	65.0 ± 16.1^{+}	87.5 ± 19.1^{+}	68.9 ± 11.3^{+}
	Trials Jockey	33.8 ± 11.3	14.6 ± 5.6	16.9 ± 5.1	25.3 ± 8.4
	Race Jockey	36.7 ± 17.1	16.6 ± 6.0*	21.4 ± 7.4*	28.1 ± 12.6
	ES (Trials)	4.1	5.9	7.1	6.2
	ES (Jockey)	0.3	0.5	1.0	0.4
Mean time difference** (s)	Trials	-0.025 ± 0.061	-0.016 ± 0.059	-0.003 ± 0.064	-0.027 ± 0.051

** Difference in time between jockey and horse minimum displacement. A positive time difference was obtained when the jockey's movement followed the horse and a negative value when the jockey preceded horse movement. Means with differing superscripts differ ($p < 0.05$) between horse and jockey at trials ($^{+}$) and between jockey riding at trials and races (*).

Appendix G
Ethical approval documentation

Ethical approval from the Massey University Human Ethics committee:

Human Ethics Application SOA 20/27 Approved

HE humanethics@massey.ac.nz
To Legg, Kylie
Cc humanethics@massey.ac.nz; Rogers, Chris; Cochrane, Darryl; Gee, Erica
We removed extra line breaks from this message.

Reply | Reply All | Forward | ...
Tue 8/09/2020 9:37 AM

HoU Review Group

ReviewerGroup
A/Pro Chris Rogers
A/Pro Darryl Cochrane
Dr Erica Gee

Researcher: A/Pro Chris Rogers
Title:Physiological demands, muscle activity and horse-rider coordination dynamics of jockeys.

Dear Christopher

Thank you for the above application that was considered by the Massey University Human Ethics Committee: Human Ethics Southern A Committee at their meeting held on 08/09/2020.
On behalf of the Committee I am pleased to advise you that the ethics of your application are approved.

Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.
If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

If you wish to print an official copy of this letter, Please logon to RIMS (http://rims.massey.ac.nz) , and under the Reporting section, View Reports you will find a link to run the Ethics Committee Report.

Yours sincerely
Professor Craig Johnson
Chair, Human Ethics Chairs' Committee and Director (Research Ethics)

Ethical approval from the Massey University Animal Ethics committee:

TV Thomas Vincent, Miralie | Rogers, Chris; Hickson, Rebecca

MUAEC Protocol 20/48 - Outcome

You replied to this message on 19/08/2020 7:47 pm.
This message was sent with High importance.

Hi Chris,

MUAEC Protocol 20/48
Physiological Demands, Muscle Activity and Horse-Rider Co-ordination Dynamics of Jockeys

Further to consideration of the above application at the recent meeting of the Animal Ethics Committee, it was agreed that your protocol may proceed.

Thanks and regards,
Miralie

Miralie Thomas Vincent
Research Ethics Advisor
Research and Enterprise
Massey University
Palmerston North
New Zealand

Phone: +64-6-9516841 (DDI), extn 83841 (internal)
Fax: +64-6-3557973
E-mail: M.E.Thomas@massey.ac.nz

Appendix H
Participant information sheet

Some aspects of the following project description were not included in this thesis. The results from the studies investigating jockey physical fitness and Jockey Exercise Training (JET) are currently being written with a view to publication post-PhD.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

School of Veterinary Science
Massey University
Palmerston North 4441
Email:k.legg@massey.ac.nz

Project Title: Physiological demands, muscle activity and coordination dynamics of jockey and horse

PARTICIPANT INFORMATION SHEET

This information sheet is to inform you about your participation in this project, which is being conducted by a research team from the School of Veterinary Science, Massey University, in association with New Zealand Thoroughbred Racing.

The research team

My name is ***Kylie Legg***. I am a PhD candidate at Massey University. This project is part of my PhD thesis, which is about the physiological demands, muscle activity and coordination dynamics of jockeys and horse. I have over 25 years of experience in the equine industry as a riding instructor, trainer and track rider as well as over 5 years' experience in varied aspects of equine biomechanical and engineering research. My academic supervisors are Associate Professor ***Chris Rogers*** (who has worked extensively with the NZTR including early training of Thoroughbred race horses), Associate Professor ***Darryl Cochrane*** (who specialises in high-performance sports training and is a strength and conditioning coach, trainer, team manager and exercise physiologist, working with Olympic and national athletes from a range of different sporting codes) and Dr ***Erica Gee*** (who is a vet with extensive experience in the field of equine science and nutrition).

Brief description of the project

Training in any sport needs to be directly related to competition performance. Whilst there is a lot of information about matching training to competition in most sports, there is very little for horse racing.

Very little is known about what the physiological demands placed on a jockey riding either track work or during a race are. While Britain and Australia have guidelines for minimum fitness levels required for jockeys to obtain their certification to be able to ride safely and to the best of their abilities, New Zealand has no guidelines. Therefore, in this project, we will be assessing the effectiveness of un-mounted strength and conditioning training on performance related physical fitness and riding skill amongst apprentice and qualified jockeys in New Zealand. To do this, we need to determine your physical fitness and characteristics before and after the training programme. This information will be used to provide guidelines for the health and safety of future jockeys.

Participant identification and recruitment

You are one of 44 healthy apprentice jockeys and established jockeys that are being invited to participate in this project.

Health screening, physiological testing and Jockey Exercise Training (JET)

All participants will undergo a health screening questionnaire before being accepted into the project. Physiological testing will be conducted at Massey University School of Sports, Exercise and Nutrition human performance laboratory. Field testing will be at your place of work. The JET programme will be described and demonstrated during Apprentice School, and you will be able to perform it at your home.

The project will take place over the course of one year during which you will be asked to attend:

- **Physiological testing** in the Massey University School of Sports, Exercise and Nutrition human performance laboratory. This will take 2 - 3 hours and will be done once before and once after the JET programme. It involves a physical test battery where you will undergo physical performance tests to assess your height, weight, balance, strength, reaction time, flexibility, power and cardiovascular fitness. More details about testing protocol are described in the next paragraph.

- **Jockey Exercise Training (JET) programme**. Based on your results in the physical testing, we will develop a personal physical training programme (less than 30 mins a day) for half of the participants to do over an 8-week period. If you are given a programme, you will be asked to perform it 5 times a week for the full 8 weeks and maintain a training log. Weekly follow-ups will be maintained during the 8 weeks. All the apprentices will participate in the JET programme, the licenced jockeys will not. Participation in this programme is voluntary.

- **Field testing.** With your trainer's permission, I will visit you at your place of work to collect field data during your daily track work, two times, once before and once after the JET programme. You will wear a portable heart rate monitor and specialised set of clothing under your normal clothing to measure the activity of your muscles whilst riding trackwork. In addition, we will attach small accelerometers to your lower back (using a belt) and to your helmet (with a strap) to measure your movements. A heart rate monitor and accelerometer will also be attached to each horse you ride. Data from all these devices will be recorded and stored by a small data logger in the form of a watch and small attachments to the clothing. The specialised clothing weighs no more than 250g and the accelerometers weigh 5 g each.

Physiological test protocol

The physiological testing will take place in our laboratory. You should come to the lab wearing clothing that is suitable for exercise (eg. shorts and a t-shirt, indoor running shoes). The day will consist of:

- Health questionnaire
- Briefing about the test protocol
- Researcher led questionnaire. This will ask you about your physical activities and experience in and outside your work as an apprentice or jockey.
- Your height, weight and foot size will be recorded.
- Your balance will be measured via a test where you will be asked to stand on one leg and reach the toe of your lifted leg to points of a star drawn on the floor. This will be repeated on the opposite side.
- Your reaction time will be measured with a Fitlight® system. This is a series of lights mounted to the wall which flash and you will be asked to press the light that is on as quickly as possible.
- Muscular strength will be assessed in a series of tests:
    - Core strength – you will be asked to hold a side plank (for both left and right sides), a horizontal position and a sitting position at 60° for as long as possible (up to 3 minutes).
    - Upper-body strength – you will be asked to complete as many push-ups to a cone as possible.
    - Lower-body strength – you will be asked to complete a vertical jump as high as possible
    - Whole-body strength – you will be asked to maintain a static riding posture for as long as possible (up to 4 minutes) on a saddle on blocks. A photo will be taken to determine your body position.
- Your flexibility will be assessed by moving your legs and hips into extended positions and their angles measured.
- Your aerobic fitness will be assessed with the beep test – running for as long as you can between two lines 20 m apart in time to recorded beeps. The time between the beeps gets shorter, every minute as the level goes up, and it tests your maximum fitness limit.

The total time to complete the physiological test protocols will be 2 – 3 hours.

Are there any risks?

As with all aspects of exercise, there is a risk of sore muscles and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also being familiarised with the protocol and equipment being used in the study. This will be provided as part of your involvement in the study.

How will you benefit?

You will each be given an individual breakdown of your results, indicating your strengths and weaknesses, providing you crucial information on areas where your riding can be improved. The JET programme will be tailored to you specifically and intended to strengthen and improve your riding performance. By increasing our understanding of the physiological demands of jockeys, it will be possible to put into place training strategies to assist you in enhancing your health, wellbeing and overall performance throughout your sporting career and beyond.

Data Management

All of the data that we collect will be de-identified for statistical analysis and will be kept strictly confidential. We will do this by storing it on a password protected computer with the hard documents kept in a locked file coded by participant number, with access limited to Kylie Legg and Chris Rogers. It will be used only in summary form for reporting or publication purposes. After five years it will be destroyed.

When the project is complete we intend to publish the group average results in a prominent journal and disseminate the results to the New Zealand Thoroughbred Racing Industry.

Your Rights – Voluntary Informed Consent

Participation is voluntary and you can withdraw at any time from the project. You are under no obligation to accept this invitation. If you do decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw without reason from the study at any point in time;
- ask any questions about the study at any time during participation;
- be given access to a summary of the project findings when it has concluded.

If you wish to receive your individual data, please contact Kylie using her email address below.

Project Contacts

Kylie Legg, School of Veterinary Science, Massey University, Private Bag 11 222, Palmerston North 4441, New Zealand.

Email: k.legg@massey.ac.nz

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 20/27. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email: humanethicsoutha@massey.ac.nz.

Appendix I

Participant consent form

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

School of Veterinary Science
Massey University
Palmerston North 4441
Email:k.legg@massey.ac.nz

Physiological demands, muscle activity and coordination dynamics of jockey and horse

PARTICIPANT CONSENT FORM

This consent form will be held for a period of five (5) years

I have read the information sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature of Participant: ______________________________

Participants Full Name (printed): _____________________________

Date: ________/________/____

Appendix J
Statements of contributions to research

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 1	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Review of physical fitness, physiological demands and performance characteristics of jockeys. Comparative Exercise Physiology, 17(4): 319-329. doi:https://doi.org/10.3920/CEP200079

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg — Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:46:51 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers — Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:15:23 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 2	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K. A., Cochrane, D. J., Bolwell, C. F., Gee, E. K., & Rogers, C. W. (2020). Incidence and risk factors for race-day jockey falls over fourteen years. Journal of Science and Medicine in Sport, 23: 1154-1160. doi:10.1016/j.jsams.2020.05.015

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg — Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:48:01 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers — Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:14:53 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 3	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K. A., Cochrane, D., Gee, E., & Rogers, C. (2020). The external workload of Thoroughbred horse racing jockeys. Sustainability, 12(18). doi:10.3390/su12187572

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:48:33 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:13:55 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 4	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2020). Jockey career length and risk factors for loss from Thoroughbred race riding. Sustainability, 12(18). doi:10.3390/su12187443

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg — Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:48:56 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers — Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:13:31 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 5	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K. A., Cochrane, D. J., Gee, E. K., & Rogers, C. W. (2021). Physical activities of jockeys during a working week. Comparative Exercise Physiology, 18(1): 75-83. doi:10.3920/cep210011

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:49:23 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:13:03 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers

In which chapter is the manuscript /published work: 6

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Legg, K., Cochrane, D., Gee, E., Macdermid, P., & Rogers, C. (2022). Physiological demands and muscle activity of "track-work" riding in apprentice jockeys. International Journal of Sports Physiology and Performance (in press).

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate:
- Describe the contribution that the candidate has made to the manuscript/published work:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg — Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:50:06 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers — Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:12:28 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Kylie Legg
Name/title of Primary Supervisor:	Prof. Chris Rogers
In which chapter is the manuscript /published work: 7	

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

Animals

- The percentage of the manuscript/published work that was contributed by the candidate: 85.00

- Describe the contribution that the candidate has made to the manuscript/published work:

The candidate was involved in the design and execution of this experiment. The candidate also collected and analysed the data. The candidate wrote the first draft of the manuscript and undertook changes and corrections under the guidance of supervisors.

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Kylie Legg — Digitally signed by Kylie Legg DN: cn=Kylie Legg, c=NZ, ou=Massey University, email=k.legg@massey.ac.nz Date: 2022.09.05 11:53:37 +12'00'
Date:	05-Sep-2022
Primary Supervisor's Signature:	Prof Chris Rogers — Digitally signed by Prof Chris Rogers DN: cn=Prof Chris Rogers, c=NZ, o=Massey University, ou=School of Veterinary Science, email=c.w.rogers@massey.ac.nz Reason: I am approving this document Date: 2022.09.05 12:11:09 +12'00'
Date:	5-Sep-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.