AN INVESTIGATION OF TRAINING, RACING, AND INJURIES OF RACING GREYHOUNDS IN NEW ZEALAND

A thesis presented in partial fulfilment

of the requirements for the degree of

Doctor of Philosophy

in

Veterinary Science

at Massey University, Palmerston North,

New Zealand.

Anna Louise Palmer

2023

ABSTRACT

Concerns about animal welfare practices, particularly the roles of animals involved in sports and entertainment, have directed public attention to the racing industry. The use of animals in racing appears to be losing societal support with solicitude about the anecdotally short career lengths, frequent racing, and high injury rates of animals in the racing industry. Nowhere is this more evident than in greyhound racing where there is a paucity of research investigating population level data on the career and racing patterns of these dogs. This thesis investigates the career duration and frequency of racing of greyhounds and assesses potential risk factors for racing injuries which may impact the longevity and welfare of racing greyhounds in New Zealand.

Descriptive analysis was used to quantify career milestones and racing frequency of racing greyhounds in New Zealand. Performance outcomes, including number of career starts, career length and the age at which greyhounds finished racing, were used to provide an insight into causes of attrition in the greyhound racing industry. Most greyhounds raced on a weekly cycle, primarily driven by the industry through opportunities to race. Greyhounds had an average of 35 career starts over a 424 day period and finished racing at a median age of 39 months.

The training practices of racing greyhounds in New Zealand were explored using a cross-sectional survey. There were no significant differences between the training practices of trainers holding a public training licence compared with those holding an owner trainer licence. The type and amount of exercise during training demonstrated specificity and homogeneity. Trainers exhibited a training micro-cycle, which was structured around the opportunities to race. Regardless of the number of times dogs raced in a week, most greyhounds had two high-intensity exercise sessions.

The type and incidence of injuries sustained during racing were identified using a retrospective cohort study. The incidence of musculoskeletal injury was 19.2 (95% confidence interval (CI) 18.6-19.8) per 1,000 racing starts, and the incidence of fatalities at the track was 1.3 (95% CI 1.1-1.4) per 1,000 racing starts.

Most injuries sustained during racing were soft-tissue injuries and most injuries affected the limbs of the greyhounds. Most of the fatal injuries that occurred at the racetrack were fractures. This study identified the need for improved conciseness around the collection and classification of injury data at the racetrack.

Logistic regression models were used to explore risk factors for the three most common types of injuries occurring in racing greyhounds on race day. Specifically, the three primary injuries were soft-tissue injuries, lacerations, and fractures. Greyhounds that raced less frequently (racing more than seven days apart) had greater odds of fracture compared to those racing more frequently. Greyhounds racing every seven days had lower odds of soft-tissue injury compared with those racing more than once a week. Dog factors such as age, country of origin and race grade were associated with increased odds of fracture. Dog and track factors, including age, race grade and racetrack were associated with increased odds of soft-tissue injury. There was a higher incidence of soft-tissue injuries than other injury types, although the consequence of such injuries were less than those for fractures.

The results of this thesis provide baseline metrics for the racing patterns, training programmes, and injury rates for racing greyhounds in New Zealand. The racing and training patterns, although mostly designed to physiologically condition the dogs for racing, contributed to the injuries sustained during racing. Improved accuracy of the data reported from race day is required to monitor the occurrence of injuries over time and allow the greyhound racing industry to address interventions that may progress towards safer racing conditions.

ACKNOWLEDGEMENTS

Ehara taku toa I te takitahi, engari he toa takitini

My success is not the work of an individual, but the work of many.

This PhD would not have been possible without the invaluable guidance of my wonderful supervisors, Dr Charlotte Bolwell, Professor Chris Rogers, Professor Kevin Stafford and Assistant Professor Arnon Gal. Thank you for your support, expertise and patience over the last few years.

A special thanks to Charlotte, for your ceaseless support over the past years. Thank you for the time you put into encouraging and teaching me and for your incredible patience and determination. Thank you for reading the countless drafts and giving me invaluable and supportive feedback with the statistical analysis and writing of this thesis.

Many thanks to Chris who offered me unwavering support and inspiration throughout the study. Thank you for always having your door open and the ‘big picture’ conversations.

I would like to thank Kevin for the enthusiasm he infused into all conversations greyhound related. Thank you for your guidance, useful discussions, invaluable knowledge, feedback, and, most of all patience, throughout my PhD journey.

Arnon; thank you for your ongoing encouragement and supervision throughout the project. In addition, I would like to thank Associate Professor Darryl Cochrane for his expertise and assistance with the interpretation of the training data.

A huge thanks also goes to those in the industry that made this research possible, without whom, valuable industry research could never take place. Thank you to Greyhound Racing New Zealand for allowing this study and for the financial support. A special thanks goes to Mairi Stewart and Jim Edwards, for initiating the project and offering their support throughout my PhD journey.

Thank you to Mike, Keith, Scott and Gavin for allowing me the countless hours in the office to watch and learn how to read a race. Your help was invaluable for learning about the greyhound racing industry. To the trainers who opened their doors and those who participated in my research – thank you for the insights and valuable information.

I would like to thank my friends and family for their constant support and encouragement. Sarah, the hours you spent helping me have been very much appreciated. I am indebted to you. One day, the answer to the 'dreaded' question will be yes.

To my parents, for their unwavering support and for helping me follow this dream – thank you so much. Your unconditional support and help during my studies has not gone unnoticed and I am forever grateful for this. You constantly inspire me through your dedication and enthusiasm. You have taught me the importance of working hard and have always encouraged me to chase my dreams. I appreciate all the sacrifices as well as the moral and financial support you have provided to help me get this far.

TABLE OF CONTENTS

ABSTRACT iii

LIST OF TABLES xiii

LIST OF FIGURES xv

LIST OF ABBREVIATIONS xvii

Chapter 1 GENERAL INTRODUCTION 1

1.1 PROBLEM STATEMENT 2

1.2 THESIS RATIONALE 2

1.3 THESIS STRUCTURE 2

LITERATURE REVIEW 4

1.4 INTRODUCTION 4

1.4.1 Greyhound racing industry 4

1.4.2 Greyhound breed characteristics 7

1.4.3 Physiology of racing greyhounds 8

1.5 WASTAGE OF RACING GREYHOUNDS 10

1.6 CAREER DURATION 12

1.7 FREQUENCY OF RACING 17

1.8 TRAINING PRACTICES 21

1.8.1 Basic principles of training 21

1.8.2 Methodologies used to capture training data 23

1.8.3 Training practices of racing greyhounds 27

1.9 INJURIES 29

1.9.1 Pathogenesis of musculoskeletal injuries 30
1.9.2 Response of bone to loading 30
1.9.3 Response of tendons and ligaments to loading 32
1.9.4 Response of cartilage to loading 32
1.9.5 Response of muscles to loading 33
1.10 COMMON INJURIES TO RACING GREYHOUNDS 33
1.11 RISK FACTORS FOR MUSCULOSKELETAL INJURY 36
1.11.1 Sex 37
1.11.2 Age 37
1.11.3 Weight 38
1.11.4 Exercise intensity 39
1.11.5 Rest periods and interruptions to training 44
1.11.6 Early exercise 48
1.11.7 Age started racing 54
1.11.8 Genetics 56
1.11.9 Trainer 57
1.11.10 Track geometry / location of racetrack 57
1.11.11 Race distance 64
1.11.12 Track surface 65
1.11.13 Number of dogs in a field 67
1.11.14 Box position 67
1.11.15 Starting position / number and individual greyhound racing style 68

1.12 SUMMARY 69

1.13 RESEARCH AIMS AND OBJECTIVES 69

REFERENCES 72

PRELUDE TO CHAPTER 2 112

Chapter 2 PATTERNS OF RACING AND CAREER DURATION OF RACING GREYHOUNDS IN NEW ZEALAND 113

2.1 SIMPLE SUMMARY 114

2.2 ABSTRACT 114

2.3 INTRODUCTION 114

2.4 MATERIALS AND METHODS 116

2.5 RESULTS 119

2.5.1 Population data 119

2.5.2 Cohort data 122

2.6 DISCUSSION 129

2.7 CONCLUSIONS 133

REFERENCES 135

PRELUDE TO CHAPTER 3 139

Chapter 3 CROSS-SECTIONAL SURVEY OF THE TRAINING PRACTICES OF RACING GREYHOUNDS IN NEW ZEALAND 140

3.1 SIMPLE SUMMARY 141

3.2 ABSTRACT 141

3.3 INTRODUCTION 142

3.4 MATERIALS AND METHODS 144

3.5 RESULTS 145
3.5.1 Respondent demographics.. 145
3.5.2 Training facilities 146
3.5.3 Training practices.. 149
3.5.3.1 Preparing young dogs for racing 149
3.5.3.2 Training race-fit greyhounds... 149
3.6 DISCUSSION.. 154
3.7 CONCLUSIONS 160
REFERENCES 161
PRELUDE TO CHAPTER 4.. 166
Chapter 4 A RETROSPECTIVE DESCRIPTIVE ANALYSIS OF RACE-DAY INJURIES OF GREYHOUNDS IN NEW ZEALAND.................................... 167
4.1 ABSTRACT 168
4.1.1 Objectives.. 168
4.1.2 Materials and methods 168
4.1.3 Results 168
4.1.4 Conclusion... 168
4.2 INTRODUCTION.. 169
4.3 MATERIALS AND METHODS 170
4.3.1 Study design, population and data collection.................... 170
4.3.2 Statistical analysis 171
4.4 RESULTS 173
4.5 DISCUSSION.. 185

4.6 CONCLUSIONS 189

REFERENCES 190

PRELUDE TO CHAPTER 5 193

Chapter 5 RISK FACTORS FOR SOFT-TISSUE INJURIES, LACERATIONS, AND FRACTURES DURING RACING IN GREYHOUNDS IN NEW ZEALAND 194

5.1 ABSTRACT 195

5.2 INTRODUCTION 196

5.3 MATERIALS AND METHODS 197

5.3.1 Study design, population, and data collection 197

5.3.2 Statistical methods 199

5.4 RESULTS 201

5.4.1 Fracture 210

5.4.2 Laceration 213

5.4.2 Soft-tissue injury 216

5.5 DISCUSSION 219

5.6 CONCLUSIONS 224

REFERENCES 226

Chapter 6 GENERAL DISCUSSION 231

6.1 OVERVIEW OF RESULTS 233

6.2 IMPLICATIONS AND RECOMMENDATIONS FOR THE GREYHOUND RACING INDUSTRY 238

6.3 RECOMMENDATIONS FOR FUTURE RESEARCH 240

6.4 CONCLUSIONS 242

REFERENCES 243

APPENDICIES 248

APPENDIX 1 Training Survey 249

APPENDIX 2 Incidence of injuries experienced by racing greyhounds in New Zealand 259

APPENDIX 3 Standardised injury reporting form 261

APPENDIX 4 Results of univariable logisitic regression screening associated with fractures 262

APPENDIX 5 Results of univariable logisitic regression screening associated with laceration injuries... 265

APPENDIX 6 Results of univariable logisitic regression screening associated with soft-tissue injuries.. 268

APPENDIX 7 Statements of contribution to doctoral thesis containing publications. 271

LIST OF TABLES

Table 2.1 The distribution (number and percentage) of greyhounds racing by age and racing class for the 2013-2016 racing seasons in New Zealand. 121

Table 2.2 Summary information for the age at which racing milestones were reached, as well as the time between registering, trialling and racing, for a cohort of New Zealand and Australian born greyhounds that raced in New Zealand during the 2013-2016 racing seasons. Differences between dogs from the two countries were tested with a Kruskal-Wallis test. 123

Table 2.3 Summary information for the age finished racing (months) by the maximum race grade reached during the dog's career for New Zealand and Australian born dogs, for a cohort of greyhounds that raced in New Zealand during the 2013-2016 racing seasons. 128

Table 3.1 Descriptive demographics, facilities used, and training methods of racing greyhounds as reported by 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand. Pearson's χ^2 or Fisher's exact test p-values are reported to demonstrate differences between the two groups of licenced trainers. 147

Table 3.2 Frequency and distance of training activities (excluding racing) of racing greyhounds as reported by 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand. 153

Table 4.1 Number and incidence of injuries experienced on race day by racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019. 175

Table 4.2 Number and incidence of the different aetiologies of injuries experienced on race day by racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019. 177

Table 4.3 Number and incidence of the anatomical location on greyhound where race day injuries occurred in racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019. 179

Table 4.4 Number and incidence of the categorised injury stand-down period (days) imposed in racing greyhounds in New Zealand between September 2014 and June 2019. 180

Table 4.5 Univariable Poisson regression for injuries experienced by racing greyhounds in New Zealand as reported by on-track veterinarians and Stipendiary Stewards (September 2014 and June 2019) (n = 213,630). 182

Table 5.1 The distribution (number and percentage) of racing starts and injuries that occurred during greyhound races in New Zealand from 10th September 2014 to 31st July 2020. 202

Table 5.2 Description of the type of injury by the severity of the injury for injuries occurring during greyhound races in New Zealand from 10th September 2014 to 31st July 2020 (n = 4,385). 205

Table 5.3 Univariable logistic regression results of risk factors for fractures, lacerations, and soft-tissue injuries in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*). 207

Table 5.4 Multivariable logistic regression results of risk factors for fractures in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*). 211

Table 5.5 Multivariable logistic regression results of risk factors for lacerations in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*). 214

Table 5.6 Multivariable logistic regression results of risk factors for soft-tissue injuries in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*). 217

LIST OF FIGURES

Figure 2.1 Frequency of racing, in terms of time between racing starts, in a cohort of 2,393 racing greyhounds followed across 95,580 racing starts between the 2013 and 2016 seasons: **(a)** Frequency histogram of the number of days between consecutive races for individual greyhounds. The highest 1% of values have been removed. The arrows above the histogram demonstrate the peaks at seven days, 14 days and 21 days respectively; (**b**) Autocorrelation function (ACF) showing the correlation in the raw residuals as a function of number of days between successive races for individual dogs. The dashed grey lines represent approximate two-sided critical bounds for the autocorrelation at $\alpha = 0.01$..125

Figure 2.2 Kaplan-Meier 'survival' curve of the age of final racing start (months) stratified by country for a cohort of racing greyhounds in New Zealand. The coloured area around each line represents 95% confidence intervals. 127

Figure 3.1 Population pyramid for age and gender of the 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand. 146

Figure 3.2. The four primary models of the training micro-cycle as described by 48 greyhound trainers across New Zealand. Racing days are highlighted by the dark grey bars and training days are shaded light grey; (**a**) low-intensity based training programme with one race (day seven) per week; (**b**) trainers give greyhounds one mid-week high-intensity training session; (**c**) low-intensity based training system with two race days per week; (**d**) training system where greyhounds race twice each week and do not participate in any workouts between race-days; (**e**) represents a typical training micro-cycle. The high-intensity training or racing load is indicated by the peaks, which are followed by a plateau of low-intensity work, which allows a period for rehabilitation and recovery before the next training load. Two of these cycles are typically followed by a rest period before the next load cycle. The racing schedule dictates the micro-cycle where greyhounds have two rest or low-intensity days to one high-intensity day........ 150

Figure 3.3 Training of the metabolic systems involved with energy production. During high-intensity workouts, the threshold at which anaerobic glycolysis becomes the predominant system for energy production is reached. Figure adapted from McArdle et al. (2010). 158

Figure 3.4 Loading and performance stages of greyhound training and racing. Young dogs are introduced to the stressors of racing during the load phase, and after 6–7 load cycles they commence racing in the performance phase. While the load cycles create a performance curve that is limited by the greyhound's physiological capabilities, with increasing number of load cycles and little time for recovery, the risk of injury increases. 159

LIST OF ABBREVIATIONS

>	Greater than
≥	Greater than or equal to
<	Less than
≤	Less than or equal to
95% CI	95% Confidence interval
ACF	Autocorrelation function
ATP	Adenosine triphosphate
C0	Class 0 (maiden class) race grade
C5	Class 5 race grade
GRNZ	Greyhound Racing New Zealand
IRR	Incidence rate ratio
IQR	Interquartile range
LRS	Likelihood ratio statistic
OR	Odds ratio
SE	Standard error

Chapter 1 GENERAL INTRODUCTION

1.1 PROBLEM STATEMENT

The racing industry in New Zealand generates an excess of $1.6 billion value-added contribution to the New Zealand economy each year (IER, 2018). It is also an industry that faces serious challenges, where increasing public awareness of, and attention to, the welfare of racing animals has fuelled ethical concerns. Attitudes of the public drive expectations and influence industry regulations that govern standards of care and management of racing greyhounds (Cobb et al., 2020). The racing industry is dependent upon gambling product for its viability, so maintaining a social license to operate is pertinent for greyhound racing to continue.

Of particular concern, for the welfare of racing greyhounds (*Canis familiaris*), is the premature loss of racing animals from the industry. This poses direct and indirect costs to the welfare of the greyhounds and the viability of the racing industry. A primary reason for early loss is injuries sustained during racing (Prole, 1976; Sicard et al., 1999; Iddon et al., 2014), however, all animals partaking in athletic endeavour are at some risk of injury. Understanding risk factors that may contribute towards racing injuries is essential if changes are to be made to minimise the occurrence of injuries.

1.2 THESIS RATIONALE

Maintaining the health and improving the welfare of racing greyhounds is essential for the future of the racing industry, however, little research has been conducted about the production of racing greyhounds. Advice on industry regulations needs to be supported by scientific evidence that the proposed changes are likely to improve the health and welfare of racing greyhounds specifically. Currently, such evidence does not exist. The rationale for this thesis is ultimately to provide information on the racing and training practices of greyhounds and the implication these practices have on injuries sustained during racing.

1.3 THESIS STRUCTURE

The thesis starts by providing background information and a critical review of the literature which identifies gaps in the existing knowledge and provides a foundation to develop the aims and hypotheses for the chapters that follow. The aims and objectives of the thesis are then presented.

The following four chapters form a series of papers which have been published during the candidature for the research degree. Given the chapters have been published in different peer-reviewed journals, there are some nuances in the formatting among chapters and there is some overlap and repetition in content. Moreover, minor amendments have been made to each the published papers to prepare the content as a thesis. The first chapter quantifies the career length of racing greyhounds and investigates racing patterns (*Chapter 2*). *Chapter 3* presents the results of a cross-sectional survey that was used to describe the training practices of racing greyhounds in New Zealand. The incidences of racing injuries were then quantified (*Chapter 4*) and this information was used to determine the injuries commonly occurring in racing greyhounds so risk factors for these injuries could be identified (*Chapter 5*). The final chapter of the thesis (*Chapter 6*) is a general discussion of the implications of the findings from the thesis which provides a synthesis, discussion, proposals for future research and conclusions.

LITERATURE REVIEW

1.4 INTRODUCTION

Over the course of racing history, the role of greyhounds as participants in sporting entertainment has received increasing criticism and contentious views due to an expansion of humanitarian understanding regarding sentience and the welfare of these dogs. Of particular concern is the 'wastage' of racing greyhounds due to anecdotally short racing careers and seemingly high rate of injuries sustained during racing.

This chapter provides a background to the research question and a critical review of the existing literature relating to racing greyhounds. Current knowledge of career milestones, frequency of racing, training practices and injuries sustained during racing is examined and used to identify gaps in the literature. While in many aspects, there is a paucity of greyhound literature, extensive research on equine athletes has been conducted in numerous fields in over the recent decades. For this reason, the horse literature has been reviewed and extrapolated to racing greyhounds where appropriate. Emphasis is placed on the importance of making informed decisions about the frequency of racing and racing injuries of New Zealand racing greyhounds.

1.4.1 Greyhound racing industry

Currently, greyhound racing is legally confined to seven countries: New Zealand, Australia, Ireland, United Kingdom, United States of America, Mexico and Vietnam (Henderson, 2022). In New Zealand, the governing body for greyhound racing is Greyhound Racing New Zealand (GRNZ) who, under the Racing Act 2003, are responsible for controlling the sport and providing support to the affiliated racing clubs. Similar statutory bodies are responsible for greyhound racing in other countries (e.g. Australia, United Kingdom and Ireland) (Beer, 2014; Dockerty, 2017).

The affiliated racing clubs are located nearby to or based at the racing tracks around New Zealand. There are currently six different operating greyhound tracks, located across both the North Island (Manukau stadium, Cambridge raceway, Hatrick raceway and Manawatu raceway) and South Island (Addington raceway, Ascot Park raceway), however, at the time the research components of the thesis were completed, there were seven operating racetracks (Greyhound Racing New Zealand, 2019). The dogs run on a sand surface and the composition of the track is similar in each region. The tracks are configured in an oval shape, however, are all unique in shape and design to some degree. Races are conducted over a range of distances (295 metres to 779 metres), which are all dependant on the location of starting boxes and finishing posts at the individual tracks. The racetracks all offer a selection of race distances, falling into the categories of: sprint (less than 457 metres), middle (between 457 metres and 599 metres) and distance (greater than 600 metres) races (Greyhound Racing New Zealand, 2017). All races are conducted in a manner where greyhounds race in an anti-clockwise direction.

In New Zealand, greyhound racing meetings are run at each track either weekly or bi-weekly (Greyhound Racing New Zealand, n.d.). The fields of dogs consist of eight starters with two reserves for each race. Greyhounds are nominated to race by their trainer, in accordance to the 'class', distance and track they are racing at. Trainers are located throughout New Zealand and must hold a training licence in order to be able to race dogs (Greyhound Racing New Zealand, 2017). There are a variety of different sized training operations, with private trainers and commercial trainers providing a range of kennels. A maximum of eight greyhounds start in each race. Once the eight starters in the field, along with two reserves, have been selected by the grader, a randomised draw selects which box number each greyhound will start from. The dogs will wear a racing rug whose colour depends on the number box they are starting from (Greyhound Racing New Zealand, 2017). While this is the scenario in the Australian and New Zealand greyhound racing scenes, in the UK and Ireland, only six greyhounds start in each race and there are two reserves per field (Dockerty, 2017). There is thought that reducing the number of starters in each race will reduce the risk of interference between runners (Eager et al., 2017).

At the beginning of a greyhound's racing career, the individual dog must be registered with Greyhound Racing New Zealand. Greyhounds are microchipped, and these are scanned during the kennelling procedures on each race day to ensure the correct dog is racing in each nominated position (Greyhound Racing New Zealand, 2017). Before they may commence their racing career, greyhounds are required to trial and reach the required time for the distance trialled. Greyhounds commence their race career as class 0 (maiden class) greyhounds. Depending on performance, they can progress through the racing grades (class 1 being the lowest and class 5 being the highest performing greyhounds). This ensures that dogs compete against other dogs of similar standard with equivalent race times. Likewise, they can move back down race grades (minimum: class 1) if they are unsuccessful in sequential racing starts. Most race meetings held across the country will offer a number of different races at the same distance but catering for different race grades. There are also a select number of 'special' races offered, such as: invited series where dogs are often required to trial and the top ten times are selected as the racing fields; or restricted age classes, where the nominations are only open to dogs of a certain age.

Dogs are encouraged to run and chase a 'synthetic hare'; a mechanical device which, in New Zealand, involves a synthetic sheepskin 'lure' attached to an extended lure arm and is connected to an intricate motorised cable system on a rail on the inside of the track. The speed of the lure is manually controlled and is driven around the track approximately seven metres in front of the fastest greyhounds in order to encourage the dogs to run. The starting boxes, where the dogs are placed for the beginning of the race, are triggered to open when the lure crosses the trip mechanism (Beer, 2014). When the dogs cross the finish line, the lure driver gradually slows the lure down, encouraging the dogs to slow and allowing them to finish 'on the lure'. In contrast, in Australia greyhounds are not allowed to 'finish on the lure'. Rather, at the end of the race, the lure accelerates away from the dogs, and the greyhounds are redirected into a 'catching pen' area (Beer, 2014).

All greyhound race meetings are chaired by Stipendiary Stewards employed by the Racing Integrity Board (previously Racing Integrity Unit), who are an independent body established under the Racing Industry Act 2020, that ensure compliance with racing rules. The Racing Integrity Board promotes high standards of integrity and animal welfare in the racing industry. On-track regulatory veterinarians are integral in ensuring the safety of racing greyhounds. As part of normal race-day procedures, veterinarians attend every race meeting and clinically examine every greyhound due to race that day before they are secured in their pre-race kennel (Greyhound Racing New Zealand, 2017). Any greyhound deemed unfit to race is thoroughly examined and subsequently scratched from the race. Stipendiary Stewards monitor and review the recording of each race and any greyhound considered to have sustained an injury is sent to the racetrack veterinarian for an inspection (Greyhound

Racing New Zealand, 2017).

1.4.2 *Greyhound breed characteristics*

The greyhound belongs to the sighthound group; a group of dogs that hunt primarily using vision and speed rather than scent and endurance (Beer, 2014; Dockerty, 2017). Since ancient times, the ability of sighthounds to chase and catch prey meant they became valued and admired assistants for hunting food (Branigan, 2004). Greyhounds first arrived in New Zealand aboard the Endeavour in 1769, and after the introduction of mammalian pests, more greyhounds were introduced in 1868 to remedy the rising population of hares (Druett, 1983). The ability to run at speed and turn swiftly led to the development of competitive coursing where the sighthounds pursued live quarry originally in an open field, but then confined in a closed arena to allow spectators to watch (Stafford, 2007). While coursing is still a popular event in some countries, including Australia and Ireland, it was banned in New Zealand in 1954. The sport we know as greyhound racing today, began in New Zealand in 1934 and has developed into a competitive event (Birkinshaw, 2006). Thompson (2003) describes early greyhound racing as "the union between the animal instinct to chase the scent of a hare and the human instinct to chase the scent of money" (Thompson, 2003, p. 27). While perhaps it is more appropriate to say the sight of the lure and the sight of money, the industry has evolved and built around the greyhound's innate ability to chase and run, to the point that nowadays it supports and is the livelihood of many people throughout the world. In more recent times, acceptance of the sport is changing, due to growing societal concerns around the animal's welfare and as awareness about the scale of the industry increases.

The greyhound has been selectively bred for centuries for the physical and behavioural attributes required to succeed in racing (Dobson et al., 1988; Stafford, 2007). Greyhounds are athletes, and while they can accelerate to speeds of 65 kilometres per hour (km/h) in a matter of seconds, racing is a physically demanding sport where there is limited control of the direction of runners on the track (Dobson et al., 1988; Stafford, 2007). The physical build and gait capabilities of greyhounds allow the animals to generate such speeds (Hudson et al., 2012). They have a lean muscular aerodynamic shaped build, with an elongated head and neck, long and powerful limbs, a deep chest and a flexible spine (Granatosky, 2019). While at lower speeds, the forelimbs support a greater proportion of body weight, this is transferred to the hind limbs, which provide vertical impulse, as speed increases (Hudson et al., 2012). The hind limbs of the greyhound have been demonstrated to support 62% of its body weight when travelling at 18 metres per second (m/s) (Hudson et al., 2012). Moreover, torque generation provided by the large hip extensor muscles of the pelvic limb allows the centre of mass of the animal to be driven forwards (Payne et al., 2005; Usherwood & Wilson, 2005; Williams et al., 2008). It is also noted that the capability of greyhounds to rapidly accelerate, from a standing start, whilst supporting minimal body weight is made possible by the ability of greyhounds to dig their digits and claws into the ground which provides a strong grip and friction (Wentink, 1979; Hudson et al., 2012). Furthermore, the arrangement of toes, where the middle two toes are longer than the outside toes, gives greyhounds the potential to grip the ground surface whilst accelerating or running around a corner (Williams et al., 2009). The locomotor muscles of greyhounds are composed of a larger proportion of fast muscle fibres compared with other dog breeds (Guy & Snow, 1981; Webster et al., 2014). Limb muscles in greyhounds have a greater muscle mass and generally contain upwards of 80% of fast-twitch muscle type IIa fibres (Armstrong et al., 1982) and are used to generate powerful bursts of movement. Racing ability has been associated with the disproportionately large weight of the heart compared to their body weight (1.25% heart:body weight ratio in greyhounds compared with 0.80% in crossbred dogs) (Schneider et al., 1964; Schoning, 1995).

Greyhounds demonstrate a rotary gallop gait where their feet land in a circular sequence, starting with the hindlimb, the contralateral hindlimb, the contralateral forelimb, and the ipsilateral forelimb (Tanase et al., 2015). The gallop demonstrated by greyhounds consists of two support phases, front limbs land followed by a flight phase, and then hind limbs land, followed by another flight phase (Dockerty, 2017). This mode of sprinting allows greyhounds to cover great distances over short time periods.

1.4.3 Physiology of racing greyhounds

Greyhounds possess numerous physiological differences from other dog breeds which allow them to sprint at great speeds, an attribute important to their racing success. Directly after an intense sprint period, heart rate, respiratory rate, blood lactate and rectal temperatures have all been noted to increase significantly ($p<0.01$) (Ilkiw et al., 1989; Pellegrino et al., 2018), demonstrating the physiological response to effort. Furthermore, during sprint distances, blood lactate reaches a threshold (>4 millimoles per litre (mmol/L)) that indicates anaerobic metabolism has been achieved (Rovira et al., 2007; Pellegrino et al., 2018). Snow et al. (1988) reported increases of blood lactate over a 235 metre sprint to 11.4 mmol/L and over a 420 metre sprint to 13.2 mmol/L. Such increases in lactate are due, in part to the higher proportion of fast-twitch type IIa muscle fibres in the trunk and limbs, which contribute to the production of lactate during periods of high-intensity exercise due to the glycolytic capacities of these fibres (Essen et al., 1975; Guy & Snow, 1981).

Significant changes to haematologic values during periods of intense exercise include increases in packed cell volume as well as an extremely low pH (Rose & Bloomberg, 1989). After periods of intense exercise, the packed cell volume remains elevated, along with red blood cell counts, white blood cell counts and total protein levels that are all higher than before the race (Lassen et al., 1986; Snow et al., 1988; Ilkiw et al., 1989; Rose & Bloomberg, 1989; Nold et al., 1991; Neuhaus et al., 1992). These parameters all return to within normal range a few hours after racing (Ilkiw et al., 1989; Rose & Bloomberg, 1989). At rest, the packed cell volume of greyhounds is already extremely high (50-65%) (Stafford, 2007), in comparison to other mammalian species, however, this increases further during racing (Toll et al., 1995). Several studies have attributed this to: a decrease in plasma volume as demonstrated by the high plasma total protein (Dobson et al., 1988; Snow et al., 1988), the ability to autotransfuse oxygenated red blood cells from the spleen into circulation during exercise (Stewart & McKenzie, 2002), or the increase in cardiac output and stroke volume (Donald et al., 1964).

High intensity and short duration exercise activity has been associated with muscle damage in greyhounds, where creatine kinase, lactate dehydrogenase and aspartate aminotransferase (muscle enzymes) have been noted to increase for several hours post exercise (Ilkiw et al., 1989). Moreover, increasing duration and race length results in significant changes in: haematocrit, arterial pH, potassium concentrations, total protein and lactate (Nold et al., 1991). The changes in the serum biochemistry observed during exercise in greyhounds are due to the physiological processes that occur.

1.5 WASTAGE OF RACING GREYHOUNDS

Greyhound racing has been a contentious issue in recent times, with one of the major threats to the racing industry being the premature loss of greyhounds from training and racing due to musculoskeletal injuries or poor performance. More specifically, wastage has been described as the number of greyhounds bred for the purpose of racing but were subsequently lost at any stage from conception to the premature end of their racing career (Jeffcott et al., 1982; Bailey et al., 1999; More, 1999; Wilsher et al., 2006). In recent years, the social legitimacy (public approval) of greyhound racing has declined significantly (Meldrum-Hana., 2015; Markwell et al., 2017; Swarbrick, 2021). Consequently, this poses a threat to the future of the industry, given that greyhound racing is reliant on wagering turnover to function as a viable enterprise (Cobb et al., 2015).

Recognition of factors that influence greyhounds leaving the racing population are essential to develop strategies to mitigate losses and support decisions regarding the welfare outcomes of these dogs. While previous research investigating losses in the Thoroughbred racing industry have used the term 'wastage' to describe the proportion of horses prematurely lost from training or racing (Jeffcott et al., 1982; Bailey et al., 1999; Wilsher et al., 2006; Flash et al., 2020), the term itself has increasingly been acknowledged as an inadequate description that does not assess the financial aspects of losses (Parkin & Rossdale, 2006; Flash et al., 2020). Additionally, colloquial use of the term 'wastage' suggests a disregard for the animals within the racing industry (Flash et al., 2020) and fails to address the productive post-racing 'careers' of racing animals (horses and greyhounds). Moreover, racing greyhounds have been perceived as having lower welfare than other working dogs, as well as Thoroughbred racehorses, with particular concern of the disposal of greyhounds at the end of their racing careers (Cobb et al., 2015; Markwell et al., 2017).

The current situation is somewhat contradictory to the concerns about the wastage and disposal of dogs, where the greyhound racing industry in New Zealand has made concerted efforts to ensure that all greyhounds are suitable for rehoming after their racing career and have the opportunity to be a companion animal. Further scrutiny identifies that the term wastage fails to capture the greyhound racing industry's need to ensure sustainable production of high-quality bloodstock, where supply does not exceed demand (Flash et al., 2020). Here, it is crucial that the industry works to ensure a large proportion of the population are rehomed as companion animals, thereby, making the term wastage obsolete (Flash et al., 2020; Flash et al., 2022b).

Nevertheless, the loss of greyhounds from the industry is one of the most important welfare concerns. Industry reviews have identified that poor breeding practices and over-breeding, in pursuit of more competitive greyhounds, has resulted in a large pool of greyhounds that lack talent or desire to race (McHugh, 2016; Hansen, 2017). An early ministerial review identified that 34.5% of greyhounds whelped (born) between 2009 and 2011 did not make it to the racetrack (Colgan et al., 2013). This was later supported by another review which found that 20-28% of greyhounds whelped between the 2009 and 2014 seasons were never registered for racing (Hansen, 2017). The rate of attrition is similar to that described in the Standardbred and Thoroughbred racing industries (Wilsher et al., 2006; Tanner et al., 2013; Shrestha et al., 2021). While this cohort of greyhounds that do not enter racing may be considered 'wastage', a recent review exploring factors contributing to the bioeconomic model for the Thoroughbred racing industry, highlighted that animal athletes are subject to natural variation and racing, by nature, identifies and utilises the elite athletes within a cohort (Legg et al., 2023). The welfare concerns therefore need not necessarily be the rate of attrition prior to racing, but rather the route taken to address the surplus of greyhounds (Stevens et al., 2022).

While a portion of the population bred to be racing greyhounds may never race, there are other factors that contribute to attrition from racing. Of greatest concern is the incidence of injuries occurring during racing, trialling and training, however, as discussed later in this review, there has been very little recent literature published on the injury rates and risk factors for racing injuries in greyhounds. An industry review undertaken in New South Wales, Australia, identified that further losses may come about through behavioural issues, where inappropriate rearing, socialisation and training practices ultimately restrict the ability for greyhounds to be rehomed at the end of their racing career (McHugh, 2016). Strategies to reduce behavioural issues and improve the ability to rehome greyhounds have been employed in all Australasian jurisdictions.

1.6 CAREER DURATION

Monitoring and quantifying career length can provide insight into the health and welfare of racing greyhounds. The average life expectancy for a greyhound is nearly 11 years (O'Neill et al., 2013). The longevity of a racing career for a greyhound measures the period during which the dog races, and is determined by the health, racing performance, and trainability of the greyhound. O'Neill et al. (2019) note that, in comparison to other breeds of dog, greyhounds are primarily bred as functional racing animals, but those suitable for domestic life are increasingly retired as pets after their racing careers. Furthermore, this increased effort to rehome retired greyhounds has come about partially in response to public concerns regarding the fate of greyhounds at the end of their career, the overall supply and demand for racing stock, as well as the welfare of racing animals in general (Flash et al., 2020; Flash et al., 2022a). However, it is important to note that only a few studies and industry reports have examined the average career length of racing greyhounds (Beer, 2014; McHugh, 2016). Outcome measures of racing performance have been noted in research that assesses attrition from the racing population, which in turn, has provided more in-depth information that enables better recognition of areas of potential welfare compromise (Velie et al., 2013c). One such aspect is sportive longevity that reflects the racing career length and quantification, which is important for understanding the context of racing greyhound turnover. In addition, high turnover rate due to short career length is associated with negative animal welfare impacts and lower economic benefits. Quantification of career duration in racing greyhounds could be used to identify factors that influence longevity with the aim of mitigating risks to reduce early losses from the racing industry (Sobczynska, 2007).

Throughout the scientific literature, performance outcomes associated with wastage in racing animals have been assessed by quantifying career duration. In short, career duration is commonly expressed as the number of racing starts, or the length of racing career, from first to last racing start. However, such measures provide different information, therefore the use of each needs to be specific to the outcome. For example, the number of racing starts provides information on career duration in terms of performance and may be a better indicator of fulfilment and racing success. Conversely, length of career gives an indication of temporality (short career versus long), but no indication of the number of starts. Hence, this approach to assessing career longevity may fail to address other issues, such as greyhounds which are predisposed to injuries, or those that have pre-existing injuries. The primary factors contributing towards wastage of racing animals and a reduced career duration are early loss due to musculoskeletal injury and lack of athletic ability (Bailey et al., 1999; Perkins et al., 2005d).

Although research assessing career longevity in racing greyhounds is limited, reports from Australia provide some insight. Results from a retrospective study of greyhounds in Victoria, Australia, demonstrated that greyhounds had a median of 10 racing starts throughout their career (Beer, 2014). While the interquartile range (IQR) across the study period was 4 – 25 starts, there was a large range (1 – 215 starts). The research offered a large sample size, including 25,240 individual greyhounds in 444,046 racing starts across a six-year period (2006 – 2011). Given that a quarter of the study population had 26 – 215 starts, it would suggest that these were the more talented dogs in which the trainers tried to maximise financial return. In this study, more than half the greyhounds had racing starts in only one calendar year. The reason for the seemingly low number of racing starts could have been due to the racing opportunities available for the greyhounds or could be due to the greyhounds racing in other states and the information not being collected as part of the research. In an industry report from New South Wales, Australia, the careers of 16,000 greyhounds were analysed; dogs had an average of 24 racing starts during their career which spanned an average of 363 days. These data had been retrieved from analysis conducted by the Greyhound Racing New South Wales, however, there were no further details of the source or validity of the data provided in the report (McHugh, 2016).

There are limited statistics on the retirement age of other canine athletes. In 2009, the Australian Working Dog Survey reported the average retirement age for dogs in sporting disciplines was 6 years of age, and that retirement age ranged from 2 to 14 years old across the Working Dog industry (Branson et al., 2009). Survey data from owners and handlers of 741 competition-level agility dogs in Finland, during one year free of agility-related injuries, reported that the length of competition career was 2.7 years (1.4 – 4.5 years) (Inkilä et al., 2022a). A subsequent study, by the same group, utilising a retrospective online questionnaire, reported that the average length of competition career was 3.1 years (1.6 – 5.0 years) for a sample of 119 dogs that had sustained an agility-related injury during 2019 (Inkilä et al., 2022b). The reasons for greyhounds retiring are likely to be complex, however, warrant scrutiny if both the biological and economical niches in which the greyhound racing industry sits are to be optimised.

Numerous studies have quantified average career duration in both Standardbred and Thoroughbred racehorses (Physick-Sheard, 1986; Tanner et al., 2011, 2013; Velie et al., 2013a; Velie et al., 2013c; Özen et al., 2021; Shrestha et al., 2021; Flash et al., 2022a). Estimates of career length are two to three years for Thoroughbred flat racing and for Standardbreds (Tanner et al., 2011, 2013). While the athletic career of racing horses is relatively short, factors attributed to influencing the length of racing career in horses, include: musculoskeletal injuries, the age at first racing start, trainer, racing performance, and sex of the horse (Tanner et al., 2011, 2013; Velie et al., 2013a; Velie et al., 2013b; Velie et al., 2013c; Shrestha et al., 2021; Flash et al., 2022a). Musculoskeletal injuries are one of the major reasons for short career length and within the racing population, account for almost a third of the reasons for loss from the industry (Bailey et al., 1999; Perkins et al., 2005d; Thomson et al., 2014; Flash et al., 2020). Risk factors for musculoskeletal injuries are discussed in a following section.

Career length can be positively influenced by trainer and early onset of training as well as competitive career (Tanner et al., 2011; Rogers et al., 2012a; Tanner et al., 2013). Racehorses started as two-year-olds have significantly more racing starts, race for more years, and have more successful careers, in terms of winnings, placings and career earnings, than horses that start at an older age (Tanner et al., 2011, 2013). There is strong evidence that exercise at an early age is beneficial in racing Thoroughbreds (Van Weeren et al., 2008; Firth et al., 2011). The application of appropriate load at an early age stimulates tissue-specific response in magnitude to the loading demands (Warden et al., 2007; Warden et al., 2014). This supported previous observations that early introduction to training has a positive association with career length and success in racehorses (Bailey et al., 1999; Velie et al., 2013a). At present, there is no scientific evidence to support, nor dispute, the appropriate load required to stimulate musculoskeletal development and aid in the longevity of musculoskeletal health in greyhounds.

Trainer has been associated with racing performance (Ely et al., 2010) and musculoskeletal injury (Parkin et al., 2005; Cogger et al., 2006; Bolwell et al., 2012a), both of which influence career longevity. Assessing the effect of trainer on career duration is not straight forward, given that horses often move between different trainers throughout their racing careers (Tanner et al., 2013; Velie et al., 2013a). Factors influenced by the trainer include the age and stage at which training milestones are met, horse-management, quality of the horse, nutrition and veterinary care; all of these contribute to racing performance and musculoskeletal health (Verheyen et al., 2009; Tanner et al., 2013).

There has been a noted association between career length and sex in racing Thoroughbreds (Velie et al., 2013c). Retirement activities in Thoroughbreds varied, depending on their sex (Shrestha et al., 2021). Entire males had significantly shorter racing careers and fewer career starts, most likely due to breeding prospects following their racing career (Velie et al., 2013c). Likewise, females were more likely to be retired within the industry for breeding, whereas geldings were more likely to leave the industry and be involved in other equestrian activities (Shrestha et al., 2021). In a genetic analysis of performance of racing greyhounds in Ireland, females had a more rapid decline in performance after 40 months of age, compared with male dogs (Täubert et al., 2007). Although the careers of their racing counterparts, Thoroughbred racehorses, have been extensively studied, little is known about the career prospects of racing greyhounds. The loss of greyhounds from racing can have welfare, ethical and economic ramifications for those involved with the industry. Knowledge of factors which are likely to increase the risk of early retirement or death can aid mitigation of such risks to ensure greyhounds achieve their optimal abilities and have a healthy career.

Primarily, retrospective studies have been used to quantify career duration in racing Thoroughbreds. Retrospective observational study designs depend on the collection of pre-existing racing industry records, and the availability of historical information from racing records allows a large sample size to be assessed. However, there are risks that the available data may not be suitable to comprehensively answer the proposed research questions. While racing industry data that supports wagering is typically complete and highly accurate, the variables routinely recorded for industry purposes are often not specific to address research questions relating to career profile, injury frequency and risk factors for injuries. Furthermore, the level of recording may have changed over time resulting in inconsistencies in the dataset. It is likely that retrospective data lacks the clarity of why a greyhound left the industry; be it either via a voluntarily or involuntarily decision of the trainer.

Career duration in racing greyhounds is constrained by both the industry regulations and biological constraints. The minimum racing age is regulated by the Rules of Racing, which was previously set at 14 months of age, but increased to 16 months of age in 2017 (Rule 19.10) (Greyhound Racing New Zealand, 2017). There are no published data on the age that greyhounds commence racing. At the other end of their career, greyhounds are constrained by a reduction in speed and performance as the dog ages. greyhounds are precocious animals and experience performance decline after peak racing age (Täubert et al., 2007), which could be the result of cumulative health damage (Sicard et al., 1999) and decreasing speed which resulted in compact racing careers. While there is no maximum age limit for greyhounds to race, anecdotally, greyhounds are retired from racing when they reach three to four years of age (Dockerty, 2017) and others report retirement at five to six years of age (Hercock, 2010). A variety of factors may influence the decision to retire a greyhound from racing. For Thoroughbred racehorses, reasons for retirement, include racing injuries, lack of competitive performance, impending injury, financial drivers, and breeding (Perkins et al., 2005d; Crawford et al., 2020b; Flash et al., 2020). Numerous studies from Australia and New Zealand have reported that most Thoroughbred retirements were voluntary, often due to poor performance or the owners request (Perkins et al., 2005b; Flash et al., 2020; Shrestha et al., 2021). With the paucity of information on career longevity in racing greyhounds, quantifying both the career length and the number of career racing starts is an important step in addressing the wastage of racing greyhounds.

Furthermore, other issues stem from the use of inadequate production and business models. Rearing puppies, from birth to racing, is considered to involve large financial and personal investment, however, no research has been conducted to determine the true cost of this process. Optimising career duration, where greyhounds have more successful and longer racing careers is considered key for the industry, not only for the welfare of the animal, but also for profitability and environmental impacts. Career duration can be influenced by a myriad of factors, and extending racing careers involves the combination of many aspects throughout the lifespan of the greyhound being successful. Nevertheless, little has been published on the current status of career longevity in racing greyhounds.

1.7 FREQUENCY OF RACING

In general, the pattern of racing is both defined and constrained by the availability of greyhounds and racing opportunities. Given the economic viability of the industry is dependent on wagering turnover, the industry is structured around maximising the number of racing opportunities (Legg et al., 2023). While this may be beneficial for economic health, there may be unintended negative consequences on the racing population. Racing frequency has been recognised as a potential concern for racing greyhounds, given that training and racing loads may contribute to injury rates and ultimately lead to wastage of racing animals.

There is a lack of scientific research investigating racing frequency and patterns of racing in greyhounds. Data has previously reported racing frequency in the context of research findings, for example in a study of risk factors for racing injuries in greyhounds in New Zealand (Stevenson et al., 2009). The authors of this study investigated the association between number of races in the 60-day period before a race and racing injuries (Stevenson et al., 2009). The study found that greyhounds had a median of three (IQR 1 – 5) racing starts in the 60-day period before a race. However, analysing frequency of racing in this manner is problematic because no information about the temporality of the racing starts was available. Information on the potential frequency of racing has been issued in an advisory document by Greyhound Racing Victoria, which describes that, on a normal racing schedule, greyhounds are raced approximately once a week, but can race every four to five days depending on how they are conditioned, noting that the interval between races is influenced by the dog's ability to recover after a race (Greyhound Racing Victoria, 2019).

Recently, greyhound racing authorities have considered and included rules placing restrictions on the frequency at which greyhounds can race. A rule preventing greyhounds from racing on consecutive days has been in place for many years in New Zealand, however, in May 2022 Greyhound Board of Great Britain introduced a rule stating that greyhounds must not run more than once in any four-day period and are not permitted to run more than six times in a 28-day period (Rule 147) (Greyhound Board of Great Britain, 2022). In September 2022, Racing and Wagering Western

Australia introduced a similar rule, restricting greyhounds from racing or trialling more than twice in a seven-day period and no more than seven times within a 28-day period (Rule L39) (Racing and Wagering Western Australia, 2022).

Numerous studies have described the frequency of racing in Thoroughbred and Standardbred horses. Perkins and colleagues (2005a) reported a median of 17 days between successive racing starts for racing Thoroughbreds in New Zealand, where horses completed 2.5 races per 100 training days. In a later study, Thoroughbreds in New Zealand started in flat races a median of five times and jump races a median of three times each calendar year (Bolwell et al., 2014a). Similarly, Standardbred pacers in New Zealand started a median of seven times every calendar year while Standardbred trotters raced a median of eight times (Bolwell et al., 2014b). A more recent study, investigating racing patterns across a 13-year period from the 2005/06 to the 2017/18 racing reason, also found that Thoroughbred racehorses in New Zealand consistently have a median of five racing starts per horse each season (IQR: 2–8 starts) (Legg et al., 2021). This study also reported a median of 16–18 days between racing starts, where the median increased over the 13-year period, while the number of horses and races decreased (Legg et al., 2021).

Another means of assessing frequency of racing that has been used throughout Thoroughbred racehorse literature is the examination of high-intensity exercise accumulated in a defined period before the race. Numerous studies have investigated prior high-speed exercise history, particularly with a focus on the association between exercise intensity and risk of musculoskeletal injury (Verheyen et al., 2005; Verheyen et al., 2006b; Boden et al., 2007). For example, studies have examined the effect of high-speed exercise accumulated over a two-month sliding window period on fatal musculoskeletal injuries (Estberg et al., 1995; Estberg et al., 1998a), high-speed exercising accumulated in the previous 60-day period (Boden et al., 2007), and high-speed exercise in the previous 12 months (Anthenill et al., 2007). The risk of injury has been associated with both an increased (Estberg et al., 1996a) and decreased (Cohen et al., 2000a) intensity of racing and a break from racing of more than 33 days (Hernandez et al., 2001). Racing frequency is an important aspect of understanding the accumulation of cyclic load; it provides an indication of accumulated high-speed workload and exposure time at high-speed. There are concerns that the frequency and duration of periods of active racing surpass the rate at which the musculoskeletal system can adapt to the stressors being applied (Estberg et al., 1998a). The relationship between injuries and exercise intensity is discussed in more detail later in this chapter.

Frequency of racing has also been associated with performance outcomes in Thoroughbred racehorses (Morrice-West et al., 2021). A recent study from Australia demonstrated that the number of wins during the previous racing season, and prize money per racing start during the previous season, were associated with frequency of racing, where 2.5 to 3.5 weeks between consecutive racing starts was associated with optimal performance, and a decline in performance was noted for horses with higher and lower frequencies of racing (Morrice-West et al., 2021). Moreover, modification of workload has been suggested as a tool to reduce injury rates, given that both high and low workloads have been associated with musculoskeletal injuries (Morrice-West et al., 2021). The authors recognised that optimising workload to prevent injuries, while having the best welfare outcome for the horse, may have poor uptake from trainers if injury reducing strategies compromise performance outcomes (Morrice-West et al., 2021). While the workload required to optimise racing performance is unknown, partially due to the lack of universality in training and racing regimes implemented by trainers, controlling bodies and regulators must consider racing opportunities and frequency of racing in the racing model.

Care must be taken when interpreting the effects of racing intensity on musculoskeletal injuries. The apparent protective effect of increased racing intensity may be due to optimal musculoskeletal tissue adaptation or may simply be due to the ability of healthier horses to race more frequently; known as the 'healthy horse' effect (Parkin, 2008). Alternatively, the association between reduced exercise and increased risk for musculoskeletal injury may be due to subclinical injury preventing the horse from racing and ultimately contributing to the injury (Parkin, 2008).

Greyhounds undergo anaerobic exercise during their sprint races, which although relatively short in duration, are metabolically demanding. Greyhound limbs contain a large proportion of fast-twitch type IIA muscle fibres (Guy & Snow, 1981; Toniolo et al., 2007) and greyhound muscle exhibits high anaerobic glycolytic potential which allows for rapid adenosine triphosphate (ATP) resynthesis to meet the energy demands of racing (Nevill et al., 1989; Kesl, 1993; Kesl & Engen, 1998; Baker et al., 2010; Pellegrino et al., 2018). Muscle glycogen has an essential role as a substrate for energy metabolism. Greyhounds demonstrate an increased ability to catabolise glycogen and the rate of glycogen breakdown in skeletal muscle has been reported as noticeably higher (25%) than the rates published for Thoroughbred racehorses performing over comparable distances (Dobson et al., 1988). Greyhounds exhibit significant post-exercise accumulation of muscle and blood lactate due to the catabolism of glycogen (Dobson et al., 1988; Ilkiw et al., 1989; Rose & Bloomberg, 1989; Nold et al., 1991; Pieschl et al., 1992; Kesl, 1993). High levels of blood lactate have been reported immediately after a race, however, the value returns to baseline within 30 minutes of the race (Rose & Bloomberg, 1989; Pellegrino et al., 2018), due to the high red blood cell volume that redistributes accumulated lactate (Gladden, 2004). Furthermore, in comparison to other breeds, greyhounds have a higher heart to body weight ratio (Schneider et al., 1964; Steel et al., 1976; Gunn, 1989; Schoning et al., 1995). The large size of the heart contributes to increased cardiac output and maximal oxygen uptake during strenuous exercise (Steding et al., 2010). Such increase in blood flow helps to remove lactate and re-establish pre-exercise metabolite concentrations more effectively than Thoroughbred horses (Harris et al., 1987; Dobson et al., 1988; Ilkiw et al., 1989).

Unlike Thoroughbred racehorses, greyhounds do not have the ability to release large numbers of red blood cells from the spleen during exercise (Persson, 1968; Rose & Bloomberg, 1989). Greyhounds have a higher resting haematocrit, haemoglobin concentration and red blood cell count than other breeds of dogs, which along with maximal exercise training, induces increases in blood volume to achieve higher oxygen uptake (Ilkiw et al., 1989; Shiel et al., 2007). Furthermore, haemoglobin in greyhounds has a higher affinity for oxygen than other mammalian species (Sullivan et al., 1994; Bhatt et al., 2011), also contributing to the increased oxygen uptake. Collectively, the physiological adaptations mentioned above contribute to the ability of greyhounds maintain a regular racing frequency.

Concern has been raised about the rest and recovery period between consecutive races. During intense exercise, exercise-induced muscle damage occurs, where muscles fatigue and weaken temporarily, muscle damage and inflammation accumulate, particularly when strenuous exercise is performed too frequently (Dupuy et al., 2018). A degree of mechanical and metabolic stress is placed on the body during high-intensity exercise, and the increased muscle metabolism increases oxygen utilisation which results in free radical formation that causes skeletal muscle damage and inflammation after strenuous exercise (Armstrong et al., 1983; Sjödin et al., 1990; Pyne, 1994; Epp et al., 2007). It has been shown that this damage can last up to 96 hours (Duarte et al., 1993). Recovery periods provide an opportunity for energy stores (glycogen) to be restored, skeletal muscle to repair, bones to remodel and repair, and metabolic by-products to be removed from muscle cells (Taoutaou et al., 1996; Dupont et al., 2004; Holmes et al., 2014). Post-exercise feeding of a high carbohydrate diet has been demonstrated to reduce the time taken to restore muscle glycogen levels (Reynolds, 1992; Lacombe et al., 2004; Murray & Rosenbloom, 2018). The time for recovery from racing has not been established in racing greyhounds and therefore an optimal racing frequency has not been determined.

1.8 TRAINING PRACTICES

While racing frequency provides an insight to the high-intensity workload undertaken by racing greyhounds, the training that occurs prior to and between racing starts also contributes to a greyhound's workload. Aspects of training practices that may influence the overall workload and load on the musculoskeletal system include the speed, frequency, distance, and duration of exercise sessions (Rogers et al., 2007; Bolwell et al., 2010). With this in mind, suboptimal training can have prominent consequences ranging from lack of physical preparation for racing resulting in poorly adapted tissue, through to predisposing greyhounds to injuries sustained during high-speed training or racing events due to excessive high-speed exercise. Therefore, capturing and understanding the training practices of racing animals is an essential step in understanding the workload of these animals, given that racing is only a portion of the total workload.

1.8.1 Basic principles of training

The primary objective for exercise and training is to promote physiologic adaptations to improve performance while preventing injuries. In order to achieve this, physical training has the following basic objectives: to delay the onset of fatigue, to maintain or improve maximum performance, to improve skills, to minimise the incidence of injuries or metabolic disorders, and to maintain willingness and enthusiasm for exercise (Rose & Evans, 1990; Marlin & Nankervis, 2002; Rogers et al., 2007). The intensity, frequency and timing of the exercise sessions will determine the nature of the greyhound's response to training (Rogers et al., 2007). In order to stimulate the appropriate physiological adaptations required for improved performance, periods of load and rest must be balanced (Rogers et al., 2007). Disturbance of homeostasis during training sessions, along with appropriate rest and recovery periods post training are necessary for long term adaptations and gaining a positive training effect (van Ginneken, 2006; Rogers et al., 2007). Training influences adaptations of the nervous, musculoskeletal, hormonal, cardiovascular and respiratory systems, resulting in increased 'fitness' (Eaton et al., 1999). The basic concept of training is that a training session will disturb homeostasis and lead to fatigue, which results in short-term adaptive responses (van Ginneken, 2006; Rogers et al., 2007). When training volume and loads are gradually increased during regular exercise periods, and the recovery period between training sessions is sufficient, the responses that occur during recovery from the training session result in an overall improvement in performance (van Ginneken, 2006; Rogers et al., 2007).

Improvements in performance can be achieved through applying two general principles related to training: the overload principle and the specificity principle. The overload principle involves athletes being exposed to a methodical increase in workload over time, while the recovery period between sessions is sufficient for tissues to repair and adapt, resulting in an overall improvement of performance (van Ginneken, 2006). It is important to note that, as performance requirements increase, there is a delicate balance between positive adaptations and increased risk of injury or reduction in performance (Lindholm & Saltin, 1974; van Ginneken, 2006; Ringmark et al., 2016). The second principle, specificity, states that training should emulate the stressors involved in racing (Bayly, 1985; Gibbs et al., 1995; Hinchcliff & Geor, 2008). It is important that racing greyhounds are conditioned to the specific demands of sprint racing on an oval track. The importance of specificity of training has been highlighted in Thoroughbred racehorse literature, where authors have recognised that high-speed workouts, over short distances stimulate the appropriate adaptations for future racing (Boston & Nunamaker, 2000; Cohen et al., 2000a).

A relationship between training practices, management strategies and musculoskeletal injuries has been noted (Crawford et al., 2020a). In Thoroughbred racehorses, risk factors for musculoskeletal injuries linked to training methods include the intensity, volume and rate of accumulation of high-speed exercise (Nunamaker et al., 1990; Estberg et al., 1996a; Estberg et al., 1996b; Estberg et al., 1998a; Boston & Nunamaker, 2000; Perkins et al., 2005d; Verheyen et al., 2005; Verheyen et al., 2006b; Vallance et al., 2013; Eckard et al., 2018; Crawford et al., 2021b), the volume of low-speed exercise (Verheyen et al., 2006b), the interaction between exercise volume and different speeds (Verheyen et al., 2005; Verheyen et al., 2006b; Morrice-West et al., 2020), the length of the training preparation (Perkins et al., 2005c, 2005d), and the period of rest between training preparations (Carrier et al., 1998; Parkin et al., 2004b; Hernandez et al., 2005; Verheyen et al., 2006b; Crawford et al., 2021a). A relationship between trainer and risk of musculoskeletal injury has also been observed (Perkins et al., 2005c; Verheyen et al., 2006a; Cogger et al., 2008a; Ely et al., 2009; Ramzan & Palmer, 2011; Reed et al., 2012). Windt & Gabbett (2017) recognised that the risk of injury is directly related to the workload, which creates various methodological and statistical challenges that have previously been overlooked. In order to understand how workload relates to injury risk, aetiological constructs must incorporate training and competition workloads (Windt & Gabbett, 2017). Throughout the Thoroughbred literature, inconsistent findings of the effects of workload on musculoskeletal injuries has limited the development of strategies which may mitigate the risk of injury. There are limited data on exercise regimens for racing greyhounds and this lack of information restricts the interpretation of how management and exercise volume could be modified to reduce the risk of injury.

1.8.2 Methodologies used to capture training data

Various methodologies have been used to explore the different aspects of training in racing Thoroughbreds. However, there is limited information on what constitutes normal training practices (Crawford et al., 2021b). Workload and training volume data vary between trainers, making it difficult to assess how they contribute to performance success and longevity (Shearman & Hopkins, 1996). Cross-sectional surveys have previously been used to obtain baseline data on the general management and training practices of racing (Bolwell et al., 2010; Legg et al., 2020; Morrice-West et al., 2020) and endurance (Bolwell et al., 2015; Webb et al., 2019) horses. Legg et al. (2020) used an online survey which was available to all registered Standardbred trainers. They described the demographics of 154 Standardbred trainers in New Zealand and focussed on the training strategies of 88 trainers with two-year-old horses in training. Comparisons between practices of public trainers and licence-to-train trainers were made when describing early training systems, reasons for involuntary breaks, training environments and variables recorded during training. Their results found that the training practices used for two-year-old Standardbreds were analogous between public and licenced-to-train trainers with the focus primarily on education, rather than racing. Another study utilised a cross-sectional survey to capture training workload in racing Thoroughbreds in Victoria, Australia (Morrice-West et al., 2020). In this study, 66 registered trainers were surveyed in order to provide information about training practices and workload. Additional information was collected on stable management, pre-training, training programmes and rest periods. The study found significant variation in volume of high-speed exercise between trainers (Morrice-West et al., 2020). Another study aimed to describe the management practices of 55 trainers of two-year-old Thoroughbred racehorses located in the Northern and Central Districts of the North Island, New Zealand (Bolwell et al., 2010). Data were collected during in-person interviews and the results found that the primary reason for training horses young was early education and that most used a standard pattern of training.

Research surveys facilitate the gathering of data from a large cohort (Jones et al., 2013) and enable rapid dissemination, administration and evaluation of information (Fowler Jr, 2014). However, as with all methods of data collection, collecting data using surveys has several drawbacks. For example, the depth of the information can be limited which can influence the ability to comprehensively examine the research topic. Furthermore, discrepancies in recall and response accuracy as well as the validity of a survey depends on the level of response (Jones et al., 2013). Depending on the method of delivery, relying on participants to complete standardised surveys can result in inaccurate and/or incomplete data (Cogger et al., 2008a; Reed et al., 2012). Correct survey design, suitable for the intended sample population, is essential to enable analysis of results.

Other equine sports have also utilised cross-sectional surveys to capture information about training. A survey of 53 endurance riders in New Zealand described the type, frequency, duration, intensity, distance and location of training sessions before the first competitive ride (Bolwell et al., 2015). Data were collected at endurance events, which resulted in a convenience-based sample and may have introduced selection bias (Bolwell et al., 2015). The results provided baseline data which could be used to guide further, more detailed studies investigating training in endurance horses.

Recently, information on the training, management and competition of agility dogs has been reported. A study in Finland utilised retrospective online questionnaires to describe the agility routines of dogs (Inkilä et al., 2022a). Owners and handlers of 745 competitive agility dogs supplied information on the training and racing routines of these dogs (Inkilä et al., 2022a). The questionnaires collected information on signalment, the agility experience of the dog and of the handler, frequency of training sessions per week, the length of training sessions (minutes), surface used in training, time off from agility, frequency of competitions and warm-up and cool-down practices amongst other variables (Inkilä et al., 2022a). The study collected information on training practices across the past year, so it is possible that nuances in training routines were not captured, due to recall bias.

The collection of training data through surveys has the ability to introduce bias to the results. There is potential for social responsibility bias to influence the results. Such bias refers to the tendency to provide answers that are considered desirable in order to make a better impression (Paulhus, 1984; Latkin et al., 2017). Another type of bias that can be introduced with cross-sectional studies is non-response bias, where intended participants choose to not respond. Non-response bias can result in an under or overestimation in the results (Cheung et al., 2017), and the reason for not responding can influence the nature of the bias (Etter & Perneger, 1997). Depending on the timing and the scope of the survey, recall bias may also influence the results in studies where historical self-reported information is collected, for example training programmes. The effects of the different sources of bias should be identified and considered whilst designing the research, so that the impacts on results can be minimised (Althubaiti, 2016).

Prospective cohort studies are another design commonly used to assess and report training methodologies. Such studies capture data from participants at the beginning of the study period and assess the outcome at some point in the future. Details about exposure are collected at the time of study enrolment and subjects are followed forward in time. Prospective data capture provides more accurate information about the exposures, confounding variables, and endpoints (White et al., 1998; Euser et al., 2009). Additionally, such studies offer an accurate documentation of events which provide a temporal relevance of data collected (Sedgwick, 2014). However, these advantages can come at the cost of efficiency given that prospective studies are time-consuming and often expensive (Euser et al., 2009). Another disadvantage of prospective cohort studies is the loss of follow-up, where participants may not complete the study which could complicate interpretation of results (Grimes & Schulz, 2002; Dohoo et al., 2009).

Numerous prospective studies have quantified the training practices of racing Thoroughbreds. In a study of two-year-old Thoroughbreds in training in New Zealand, training records were collected for across a 13–15 week period (Rogers & Firth, 2004). The trainer recorded location of training session, time, distance and the subjective gait. While they did quantify the workload for a group of Thoroughbreds, data were presented for just seven horses under one trainer (Rogers & Firth, 2004). Perkins and colleagues (2005a) gathered information from 20 trainers and 1,571 horses using a prospective longitudinal study in order to describe training patterns for a population of Thoroughbred racehorses in New Zealand. They reported the number of spell days and training days, as well as the duration of training preparations. They also categorised training activities, scoring training depending on the intensity. However, detailed information about the precise exercise undertaken, including distance travelled and training location, were not collected (Perkins et al., 2005a). Cogger (2006) utilised a prospective cohort study in which training activity data were collected across a 27-month period for 451 Thoroughbreds in training with 14 trainers in New South Wales, Australia. Data were collected on training preparations and the intensity of activity completed on each training day, while investigating risk factors for musculoskeletal injuries. However, the adjustable nature of training programmes was not captured (Cogger, 2006; Cogger et al., 2008b). In a series of studies, Bolwell and colleagues (2012) collected detailed data regarding daily training activities for young Thoroughbreds from trainers in New Zealand in order to establish if there were associations between exercise regimes and training and racing performance (Bolwell, 2011; Bolwell et al., 2012a; Bolwell et al., 2012b; Bolwell et al., 2013). They collected information on the type of exercise, the duration of the exercise and the distance worked at different speeds. Reed and colleagues (2012 & 2013) collected daily training information in order to identify exercise-related risk factors for joint injuries in young Thoroughbreds. Data were collected from a convenience sample of 13 trainers, where the daily exercise (type of exercise and distance) of each of the 647 horses enrolled in the study was recorded. They described the distance exercised at canter and high-speed over different time periods, adjusting for sex of the horse, age of the horse and trainer. The authors acknowledged that the methods relied on trainers providing accurate records of daily training activities for their horses and validation of such data would prove difficult (Reed et al., 2013). More recently, a large, prospective study conducted in Queensland, Australia, involved weekly interviews with 26 trainers for more than a year (Crawford et al., 2021b). They described training methods for 535 two-year-old Thoroughbreds, investigating differences between different sized stable operations. Data were collected on length of rest periods, length of pre-training, length of preparations and training activities. They investigated the cumulative days, average days per week, cumulative distance and average distance per week of low-speed exercise, non-ridden exercise and high-speed exercise for the first, second and third or higher preparations. Moreover, they reported the number and proportion of horses that reached training and racing milestones, as well as the time taken to reach the milestones (Crawford et al., 2021b).

1.8.3 Training practices of racing greyhounds

Kesl (1993) has provided the most detailed account of what was considered to be typical training practices at the time, especially for young greyhounds before they commence racing. For young dogs (<12 months old), the ability to run in large open spaces facilitates adaptation of the musculoskeletal system to galloping and allows pursuit skills to be enhanced. Often, dogs of this age were introduced to mechanical lures in a bull ring (a small circular training area with an inside rail on which a mechanical arm with a lure can be operated) in order to encourage pups to chase (Kesl, 1993). The next phase of training (approximately from 12 months of age through to when they commence racing), greyhounds would typically begin structured training sessions. Initially, this would involve walking for anywhere between 15–60 minutes usually twice a day and this period would last for three to four weeks, either on the road, on treadmills or in rotary walking machines. This phase promotes baseline conditioning and prepares the greyhounds for the subsequent high-intensity work. For the following three or four weeks, most greyhounds will then begin sprint work where they will typically run 50–200 metre hand slipped sprints on every second day, initially encouraging the dogs to run at 70–80% race pace. The length of the sprint is gradually increased and attempts to increase the intensity are made by introducing a lure for the dogs to chase. In the latter stages of this training phase, dogs are introduced to the formalities of racing, including box training with starting boxes, training with other runners and introduction to training at a circular track. Kesl (1993) notes that training on circular tracks will often occur with gaps of seven to ten days between consecutive sprints whereas training on straight tracks occurs more frequently, usually every two days. Training and trialling on a circular racetrack is essential to condition the greyhounds to sprint racing, for remodelling of bone and strengthening of muscles in response to running around a curved track (Kesl, 1993). The work suggests that after four to six trials or full gallops on a circular racetrack, most greyhounds are ready to commence racing. Once racing, less time is spent training although there is variation amongst trainers. Kesl (1993) provides a comprehensive training guide for young greyhounds, however, there is no reference as to where this information came from. Moreover, they focus very little on the training practices once greyhounds commence racing and provide no evidence for similarities or differences that may occur at trainer or dog level. Caution must be taken when interpreting the protocol described by Kesl (1993), given that the study was conducted several decades ago and there have likely been changes to the management, training and racing of greyhounds since the study was completed.

A small number of studies mention a training protocol used in the study design. While studying the effects of exercise on myocardial function on a group of 20 greyhounds sourced from different trainers, Rippe and colleagues (1982) acknowledged the undoubted variation in the dogs training history due to coming from different trainers. They did, however, point out that training procedures tended to be fairly uniform amongst trainers, and stated what they would consider a ‘normal’ training schedule to include (Rippe et al., 1982). The training of greyhounds between 5–11 of age months would typically entail light but incremental exercise in long runs and from 11–15 of age months this would increase to approximately one hour speed training workouts on five days each week. During this period, the daily routine of speed work would involve two to three 500 metre solo sprints, followed by three to four 500 metre sprints with a group of dogs. This continued until the dogs began racing at between 15–18 months of ages, however, no further details were supplied around the racing or training schedule once dogs had started racing (Rippe et al., 1982). While this study provides an approximation of the high-speed exercise undertaken each week, it did not provide details of low-speed exercise, nor examine differences in training programmes between dogs or trainers. Lonsdale and colleagues (1998) described the training practices for 39 greyhounds as part of their study which examined echocardiographic parameters. They considered training to be routine exercise involving weekly trialling and racing as well as daily walking. Further, they considered the average training practice to include 20 minutes of walking twice daily and galloping 300 metres twice a week (Lonsdale et al., 1998). Hill and colleagues (2001) investigated the effects of racing and training on serum thyroid hormone concentrations in a group of nine racing greyhounds. For a six-month period, prior to the experiment commencing, the dogs were exercised for 15 minutes twice daily in a 30 metre by 30 metre grass paddock and each galloped 500 metres around an oval, sand-clay track with another dog up to twice a week (Hill et al., 2001). Although the prescribed training methodology was described, there was a lack of specific information provided on the schedule of gallops within the weekly period and how this may fit in around a racing schedule. The study had a small number of dogs that were no longer racing and all greyhounds followed the prescribed training protocol which was standardised in order to answer the research question (Hill et al., 2001).

There is a paucity of comprehensive and consistent information regarding the training practices and workload of racing greyhounds in the scientific literature. There is a need for further data on the structure of training programmes, training intensity and volume of high-speed exercise in order to establish the impact that training may have on the racing industry. Moreover, the sport has developed in recent years, with increasing focus on selective breeding (Denny, 2008; Dockerty, 2017), in an attempt to increase dogs capable of faster competition speeds, which may have affected training practices.

1.9 INJURIES

Globally, the greyhound racing industry has faced an imperilled social license in recent years over animal welfare concerns. Increasing scientific knowledge of animal welfare and the evolving public perception of the use of animals for human entertainment has drawn attention to injuries sustained by racing greyhounds. There has been very little recent literature published on the injury rates and risk factors for racing injuries in greyhounds. The horse has been recognised as a good model for determining the influence of exercise on the musculoskeletal system (Tidswell et al., 2008) and for that reason, horse literature has been reviewed and extrapolated to racing greyhounds where appropriate.

1.9.1 Pathogenesis of musculoskeletal injuries

The musculoskeletal system experiences substantial physical demands during training and racing (Evans et al., 1992). Musculoskeletal tissues respond to mechanical loading through adaptive changes which alter the physiological load tolerance of the tissue (Kim et al., 2009). While increased loading results in hypertrophy, substantial overloading can lead to degradation of tissues; increasing the incidence of microinjury and predisposing the tissue to clinical lesions (Kim et al., 2009; Martig et al., 2014). The volume (intensity, duration and frequency) of exercise determines the response of the tissue, through either positive adaptations or pathological changes (Rogers et al., 2007). Musculoskeletal injuries can result from a single load which exceeds the physiological threshold of the tissue or may be the result of acute manifestation of chronic tissue damage that has accumulated during racing and training (Anthenill et al., 2007; Muir et al., 2008; Martig et al., 2014).

1.9.2 Response of bone to loading

Bone tissue is dynamic; it models and remodels on the basis of the loads it receives (Wolff's Law and the mechanostat model) (Frost, 1987). Bone modelling involves sequential phases of bone formation and bone resorption which alter the size and shape of the tissue (Burr et al., 1989; Riggs & Boyde, 1999; Seeman, 2009). The "specificity" of exercise is important to permit functional adaptation of bone; bone models and remodels in response to its loading environment (Lanyon, 1992), and the loads experienced during racing must be encountered during training in order for the bone to adapt sufficiently to protect against injuries (Bennell et al., 1996; Whitton et al., 2010; Martig et al., 2020). Mechanical loading, through physical activity, enhances bone structure and helps to build bone mass. Increases to both cortical thickness in long bones and compressive strength of trabecular bone, as a result of bone adaptation, increase the fatigue life of the bone (Boyde et al., 2001; Warden et al., 2005; Lynch et al., 2011; Martig et al., 2014). The absence or reduction of mechanical loading results in bone adaptation through net resorption (Zerwekh et al., 1998; Whitton et al., 2010). This has been documented in Thoroughbred racehorses where studies found a decreased bone density of the diaphysis and increased porosity of the condyles of the third metacarpal bones in horses resting from training (Whitton et al., 2010; Firth et al., 2012; Martig et al., 2014). Damaged bone is repaired through remodelling, where fatigued bone is resorbed by osteoclastic activity and replaced through osteoblastic activity (Mori & Burr, 1993; Bentolila et al., 1998). Rates of remodelling are suppressed during periods of high-intensity exercise and microdamage can accumulate with further loading cycles (Boyde, 2003; Whitton et al., 2013; Holmes et al., 2014). Bone resorption occurs rapidly and is followed by the slower phase of bone replacement, which can take months to regain previous strengths (Clarke, 2008; Boivin et al., 2009). During resorption, the bone is weakened due to increased porosity and is more susceptible to failure that fully adapted bone, particularly during the lag between resorption and replacement of bone (Martig et al., 2014). While periods of inactivity are important to allow increased rates of bone turnover and to maximise bone adaptation, return to fast work after rest periods must be well managed (Carrier et al., 1998; Whitton et al., 2010; Martig et al., 2014).

Accumulated load has been implicated in the pathogenesis of fractures in racing greyhounds throughout veterinary literature (Muir et al., 1999; Johnson et al., 2000; Tomlin et al., 2000). Cyclic loading results in degradation of the components of bone which can eventuate in fatigue failure (Burr et al., 1997; Martig et al., 2014). Microdamage forms from either repetitive loading during intense exercise in well adapted bone, or low-intensity exercise in poorly adapted bone (Bennell et al., 1996; Stepnik et al., 2004; Whitton et al., 2010; Crawford et al., 2020b). Microdamage begins at the molecular level with the breakdown of structural components, which extends with the application of further loads, to diffuse damage and microcracks which can result in complete failure or fractures (Carter & Hayes, 1977; Boyce et al., 1998; Danova et al., 2003; Zarrinkalam et al., 2005; Herman et al., 2010). In racing greyhounds, this has been demonstrated in central tarsal bone fractures where microdamage has been observed at the site of fracture (Muir et al., 1999).

Bone, like other materials, has a finite loading capability and the fatigue life of bone is dependent upon the magnitude and number of applied loads (Danova et al., 2003; Martig et al., 2014). Increasing the magnitude of load, reduces the number of loading cycles to failure (Carter et al., 1981,Martig et al., 2013; Martig et al., 2014; Morrice-West et al., 2021). Significant microdamage has been recorded in the forelimbs of skeletally mature canine mongrels which were subjected to three point bending at 1,500 or 2,500 microstrain for 10,000 cycles (Burr et al., 1985; Mori & Burr, 1993). There have been no studies attempting to quantify the number of load cycles at which failure occurs in racing greyhounds, however, an earlier study of Thoroughbred racehorses in the United Kingdom identified there was is an increased likelihood of failure when 7,700 loading cycles at canter and 880 load cycles at gallop were accumulated over a 30-day period (Verheyen et al., 2006b). More recently, this has been challenged by research in Australia that found most training programmes include high volumes of galloping which far exceed the previously reported levels shown to increase risk of fracture in racing Thoroughbreds from the United Kingdom (Morrice-West et al., 2020). Despite the large difference in volume of galloping, race-day catastrophic musculoskeletal injuries were not significantly different between the United Kingdom and Australia (Boden et al., 2006; Morrice-West et al., 2020). Morrice-West and colleagues (2020) suggested that the risk of failure may be dependent on the loading regime (Holmes et al., 2014), highlighting the importance of transitioning horses from rest to race-level activity as well as the specificity of the loading cycles (Morrice-West et al., 2020).

1.9.3 Response of tendons and ligaments to loading

Tendons play a role in storing and recovering mechanical energy to contribute to the efficiency of locomotion and act to position the limb correctly during locomotion (Woo et al., 2000; Birch, 2007; Thorpe et al., 2010). During growth, tendons and ligaments adapt to the mechanical forces imposed, through increases in volume and cross-sectional area (Kasashima et al., 2002), however, once mature, the adaptation of these tissues to loading is minimal and occurs at a very slow rate (Van Weeren et al., 2008). Tendon failure can be caused due to cumulative microfibre injury from repeat high frequency loading, which exceeds the rate at which the tendon is repaired (Schaaf et al., 2009).

1.9.4 Response of cartilage to loading

Articular cartilage provides a smooth surface to aid in the transmission of loads by reducing friction (Sophia Fox et al., 2009). Under normal joint loading, cartilage deforms to maximise the surface area and reduce the amount of stress within the cartilage (Bullough et al., 1973; Brandt et al., 2009). Cartilage is understood to be able to withstand a high number of cyclic loads. During loading, the forces experienced in the joints cause an increase in pressure of interstitial fluid which, in turn, causes fluid to leave the extracellular matrix until the material is fully compressed. The interstitial fluid flows back into the extra cellular matrix when the load is removed. The level of deformation is dependent on the magnitude, frequency and duration of the load. High impact loading inhibits protein and proteoglycan synthesis resulting in degradation (Jeffrey et al., 1995; Quinn et al., 2001). Increased strain applied to cartilage results in increased stiffness of articular cartilage (Langelier & Buschmann, 2003). Under high loading, energy storage in cartilage increases with loading frequency, while energy dissipation response remains the same (Fulcher et al., 2009). At greater frequencies of high-impact loading, cracks can form within the calcified cartilage as a means of releasing the stored energy (Sadeghi et al., 2015; Mahmood et al., 2018). The rate of cartilage turnover is very slow (Van Weeren et al., 2008) and articular cartilage reaches its mature thickness while animals are growing.

1.9.5 Response of muscles to loading

Muscles work by contracting or relaxing to create movement. Excessive load, inadequate recovery or overtraining can result in soft-tissue issues (Gabbett, 2003, 2004; Gabbett & Domrow, 2007). Muscles are susceptible to bruising, tearing or rupturing during high-intensity exercise. Exercise-induced muscle fibre damage, detected by the presence of myoglobinuria, has been reported in racing greyhounds (McNicholl et al., 2016). Moreover, increases in plasma muscle enzyme activities have been reported up to three hours after strenuous exercise (Ilkiw et al., 1989). During intense exercise, exercise-induced muscle damage occurs, where muscles fatigue and weaken temporarily, muscle damage and inflammation accumulate, particularly when strenuous exercise is performed too frequently (Dupuy et al., 2018).

1.10 COMMON INJURIES TO RACING GREYHOUNDS

Injuries sustained by racing greyhounds have economic, emotional and welfare consequences, and are concerning for racing control authorities, trainers, owners, veterinarians and spectators (Beer, 2014). The aetiology of injuries is multifactorial, with a complex range of factors that can lead to a greyhound becoming injured during or after a race, as with other species of high-speed athletes, and as described by Hansen (2017, p. 43) “greyhound racing is inherently dangerous. Greyhounds race at high speeds in conditions which make injuries almost inevitable”. While greyhounds are agile, high-speed athletes, they experience injuries to parts of the musculoskeletal system involved in locomotion and acceleration due to the high forces generated by ground-limb contact, especially while travelling around bends, which leads to increased predisposition to injuries (Hayati et al., 2017b). Numerous studies outline the types and rates of injuries commonly sustained by racing greyhounds (Prole, 1976; Sicard et al., 1999; Stevenson et al., 2009; Beer, 2014; Iddon et al., 2014). The recognition of these injuries is essential to assess likely causes and address where improvements can be made to minimise loss (Stevenson et al., 2009).

The nature of greyhound racing, anti-clockwise around an oval track at high speed, predisposes these dogs to specific racing injuries. Numerous studies have identified factors contributing to the occurrence of injuries to include: speed; race distance; grade of race; fitness of the dog; degree of camber and radius of the bends; track surface material and conditions; track maintenance; and the weather (Davis, 1973; Hickman, 1975; Prole, 1976; Cook, 1998; Sicard et al., 1999). However, there are only a small number of published reports that document the frequency of injuries in greyhounds.

Rapid acceleration exerts enormous strain on the musculoskeletal system and inadequate warm-up of the muscles prior to exercise is thought to predispose greyhounds to the development of muscle injuries (Strickler et al., 1990; Dockerty, 2017). Despite warm-up practices being advocated by veterinarians and sport scientists, little pre-race warm-up is performed in greyhounds and the type and amount of warm-up is inconsistently applied (Windred et al., 2007). Racing greyhounds are susceptible to muscle ruptures, sprains, haematomas and generalised muscular pain (Davis, 1967; Davis, 1973). The most commonly injured muscles are the gracilis muscle in the pelvic limb (Prole, 1976) and the triceps in the thoracic limb (Prole, 1976). These two muscles are prone to rupturing (Dockerty, 2017). While the prevalence of right and left tricep injuries are similar (Davis, 1973; Prole, 1976), the gracilis injury is more commonly seen in the right pelvic limb likely due to the additional stresses placed on the right hind leg around the bends (Vaughan, 1969; Hickman, 1975; Prole, 1976). Greyhounds occasionally pull-up either during or after a race demonstrating muscle cramping, which has been associated with dehydration, lack of warming up, or an imbalance of electrolytes (Blythe et al., 2007).

In racing greyhounds, the digital flexor tendons are prone to bruising injuries, in part, as result of their location on the palmar surface of the metacarpal bones (Davis, 1967; Prole, 1976). A total of 75% of flexor tendon injuries occur in the left thoracic limb of racing greyhounds (Prole, 1976). Ligament injuries are also commonly seen and include: sprains to the dorsal radiocarpal ligament (Guilliard, 1997); sprains or disorders of the short radial collateral ligament (Guilliard, 1998; Guilliard & Mayo, 2000) avulsion fractures of the oblique and straight short radial collateral ligaments (Guilliard & Mayo, 2000); sprains or ruptures of the dorsal tarsal ligaments (Guilliard, 2003); and rupture of the plantar tarsal ligaments (Guilliard, 2003). Degenerative changes to the support structures of the carpus and tarsus have been reported (Guilliard, 1998, 2005). Radiographs of 100 racing or retired British greyhounds (Guilliard, 1998) identified a 14% incidence of enthesiopathy (disorder of the muscular or ligamentous attachment to bone) of the origin of the straight part of the short radial collateral ligament, with a significant over-representation of the left carpus. The disorder, however, was not found to be of clinical significance, and there was no evidence of any adverse effects on performance.

Fractures are commonly reported in racing greyhounds (Prole, 1976; Sicard et al., 1999) and are primarily presented in the pelvic limb (Gannon, 1972). Prole (1976) reported the prevalence of fractures is 12% of the total injuries, and comprise 21% of pelvic limb injuries and 9% of thoracic limb injuries (Prole, 1976; Dockerty, 2017). Fractures in racing dogs are dissimilar to those noticed in other domestic dog breeds (Dockerty, 2017), as they primarily result from bone fatigue due to cyclic compressive loading and as a consequence, the microdamage in the bone is unable to be repaired before the stress fracture occurs (Gannon, 1972; Taylor, 1997, 1998). Stress fractures in racing greyhounds have been described in the central tarsal bone (Gannon, 1972; Boudrieau et al., 1984a, 1984b; Muir et al., 1999; Emmerson et al., 2000; Johnson et al., 2000; Tomlin et al., 2000; Bergh et al., 2012), metacarpal and metatarsal bones (Gannon, 1972; Bellenger et al., 1981; Emmerson et al., 2000; Johnson et al., 2001; Lipscomb et al., 2001) and the acetabulum (Wendelburg et al., 1988).

Racing greyhounds demonstrate the fatigue fracture model of injury due to microcracking as well as complete fracture occurring in the right central tarsal bone (Johnson et al., 2000). During racing, the outside (right) hind limb is subjected to asymmetric cyclic compressive loading due to the anti-clockwise direction of racing around a circular track (Johnson et al., 2000). While racing around a bend, loads are concentrated on the lateral aspects of the inner limbs and the medial aspects of the outer limbs (Innes & Clegg, 2010). Furthermore the application of cyclic stresses from racing and training evokes adaptive remodeling response in bones affected with fatigue fractures (Muir et al., 1999). Changes in mineralisation of bone have been well documented in greyhound stress fractures (Muir et al., 1999; Johnson et al., 2000; Johnson et al., 2001).

1.11 RISK FACTORS FOR MUSCULOSKELETAL INJURY

Injuries sustained during racing pose a significant welfare concern for racing industries internationally. To address welfare concerns and reduce the number of injuries sustained during racing, the possible risk factors need to be identified. Causal and mechanistic understandings are required to inform appropriate actions that can act as interventions to athletic injuries (Hulme & Finch, 2015; Kalkhoven et al., 2020). An epidemiological and multifactorial approach to understanding causation of injuries has recognised that each causal mechanism involves the combined action of multiple contributing factors (Lash et al., 2020). However, numerous challenges that hinder the ability to develop an intricate understanding of injury causation, in part due to the multifactorial nature and complexities of interactions between various environmental and biological factors (Fonseca et al., 2020; Lash et al., 2020). Consequently, single risk factors are unable to sufficiently predict causation of injury, and given the multifactorial nature of athletic injuries, controlling for other risk factors using multivariate techniques are recommended (Meeuwisse, 1994; Meeuwisse et al., 2007; Windt & Gabbett, 2017). Investigating injuries in racing greyhounds is no different, and greater understanding can be drawn from previous studies which have utilised incidence and injury counts to determine potential risk factors for greyhound racing injuries (Sicard et al., 1999; Beer, 2014; Iddon et al., 2014).

1.11.1 Sex

Research investigating the association between sex and risk of musculoskeletal injury in racing greyhounds has provided inconsistent results. A retrospective study of greyhounds racing in the North Island of New Zealand found that bitches had a higher risk of injury-fatality compared to male dogs, although injuries were not separately analysed by aetiology or anatomical location (Stevenson et al., 2009). In an earlier study, Gannon (1972) reported no difference in the number of tarsal fractures between sex, however, did note a preponderance in the incidence of metacarpal fractures between sexes. The higher incidence of metacarpal fractures in male dogs was, in part, attributed to the greater body weight at 12 to 24 months of age (Gannon, 1972). This research was a review of observations made by a veterinarian while treating and diagnosing a series of 100 consecutive fractures of racing greyhounds presented to a veterinary clinic, rather than from research with more rigorous methodologies and analyses (Gannon, 1972; Beer, 2014).

Differences in the management of injuries between dogs and bitches may bias the interpretation of incidence of fatal injuries. For example, owners may be prepared to invest in a salvage operation for a seriously injured bitch if her breeding prospects are good. This effect has been hypothesised as influencing the difference in risk of fatal injury in males compared with female racing Thoroughbreds (Estberg et al., 1998b).

1.11.2 Age

Several studies have found an association between race age and risk of musculoskeletal injuries in racing greyhounds. Stevenson and colleagues (2009) reported an increase in odds of injury and fatality with 12-month increments in dog age. Analysing all musculoskeletal injuries together may have influenced the results from this study as different injuries are likely to be more prevalent at different ages. Moreover, analysing the risk of injury in annual increments of age, in racing greyhounds, would not provide the most robust information given that, anecdotally, the racing career length for greyhounds is ‘relatively short’ and has not been quantified in the literature. In a study investigating tarsal fractures of racing greyhounds in Victoria, Australia, increasing age was associated with increased risk of injury (Beer, 2014). From 27 months of age onwards, age categories had an increased odds of serious tarsal injury compared to the reference group of less than 21 months of age; for some categories the odds were four or five times that of the reference group (Beer, 2014). The high incidence of tarsal fractures in racing greyhounds has been attributed to the accumulation of microdamage and therefore providing extensive evidence of a fatigue fracture model (Muir et al., 1999; Tomlin et al., 2000).

In racehorse literature, the relationship between musculoskeletal injuries and age in racehorses can be complex and often includes transformation of the data in order to be accurately modelled (Estberg et al., 1996b; Rosanowski et al., 2017a). A number of studies have found no association between age and musculoskeletal injuries (Estberg et al., 1996a; Hernandez et al., 2001; Parkin et al., 2004b; Parkin et al., 2005; Anthenill et al., 2006; Verheyen et al., 2006b; Bolwell et al., 2017; Sun et al., 2018). Some studies have reported a complex relationship between age and musculoskeletal injury, such as an initial increase in risk of injury followed by a decrease or plateau (Estberg et al., 1996b; Rosanowski et al., 2017a), and interactions between race type and race age (Estberg et al., 1998b) as well as age started racing and age at death (Rosanowski et al., 2017a; Hitchens et al., 2019). An association between increasing age and increased risk of musculoskeletal injury has been noted in numerous studies (Cohen et al., 2000a; Perkins et al., 2005c; Boden et al., 2007; Georgopoulos & Parkin, 2016; Rosanowski et al., 2017a). With increasing age comes increasing exposure to exercise and training and thus, accumulation of cyclic load, making interpretation of the true risk of age troublesome. It is also possible that there is an aspect of selection bias when examining risk of injury in horses across different ages. It is likely that the horses still racing at an older age are generally healthier than their counterparts that were removed from training at a younger age (Sun, 2016).

1.11.3 Weight

There is a gender bias between the body weight of male dogs and bitches, where dogs have been reported to have a higher median body weight (32.9kg) than bitches (27.7kg) (Beer, 2014). Weighing was introduced to counter attempts to influence the outcome of a race. Greyhounds are weighed during the pre-race kennelling process where deviations from the previous weigh in (within last 28 days) have implications either to the dog being permitted to start that day or can lead to a penalty fine (Beer, 2014). Anecdotally, the desirable weight for racing greyhounds is

26-34kg (McNicholl et al., 2016), however, each individual greyhound has an ‘optimal’ race weight at which they perform best (Beer, 2014). While racing in the anti-clockwise direction, the left thoracic limb impacts the grounds at great force (2.2 times the animal’s body weight) (Dockerty, 2017). Increases to racing weight are believed to increase the risk of injury (Davis, 1973) where physical forces applied to joints at speed or on turns increase with increasing body weight (Ireland, 1998; Beer, 2014). A study of serious tarsal injuries in greyhounds racing in Victoria, Australia, identified body weight as a risk factor for serious tarsal injuries (Beer, 2014). Compared to the reference group of 25.0–27.4kg, the odds of serious tarsal injury were higher in all heavier groups (Beer, 2014). Conversely, Sicard and colleagues (1999) found that body weight was not a significant risk factor for injuries in racing greyhounds. In respect to career length and patterns of racing, variations in weight, for an individual greyhound, may be correlated to career ending injuries; however, more research is needed in this area.

1.11.4 Exercise intensity

The speed, distance and frequency of exercise, including racing and training sessions, have been implicated as significant risk factors for musculoskeletal injuries in racehorses (Stover et al., 1992; Estberg et al., 1998a; Cogger et al., 2006; Verheyen et al., 2006b; Parkin, 2008; Whitton et al., 2018) and there has been a strong interest in optimising training and management strategies to reduce musculoskeletal injuries (Morrice-West et al., 2020; Morrice-West et al., 2021). However, the exact nature of the interaction between high- and low-speed exercise as well as rest periods with injury remains unclear (Carrier et al., 1998; Parkin et al., 2004b; Verheyen et al., 2005; Verheyen et al., 2006b; Crawford et al., 2020a). While a large body of research has investigated the relationship between exercise intensity and musculoskeletal injuries in Thoroughbred racehorses, there has been little research focused on this association in racing greyhounds. A retrospective cohort study investigating risk factors for musculoskeletal injuries in New Zealand racing greyhounds reported a decrease in the odds of injury for every additional start made within the previous 60 days (OR: 0.96, 95% CI: 0.92-0.99) (Stevenson et al., 2009). The median number of starts over a 60-day period was three (IQR 1-5), so it is difficult to interpret the effect of exercise on musculoskeletal injury without the temporal relevance of racing starts or knowledge of the greyhound’s training history.

Exposure to high-speed exercise has produced varying results as a risk factor for musculoskeletal injuries where both increased and decreased cumulative distance of high-speed exercise have been identified as risk factors in Thoroughbred racehorses (Estberg et al., 1995; Estberg et al., 1998a; Estberg et al., 1998b; Cohen et al., 2000a; Parkin et al., 2005; Perkins et al., 2005c; Verheyen et al., 2005; Anthenill et al., 2007; Boden et al., 2007). Additional factors, including the association between high-speed exercise and low-speed exercise, the length of the training preparations and length of rest periods, contribute to the complex relationship between exercise intensity and risk of injury (Carrier et al., 1998; Hernandez et al., 2001; Parkin et al., 2004b; Hernandez et al., 2005; Verheyen et al., 2005; Cruz et al., 2007). The balance between load and tissue capacity plays a major causative role in injury (Kibler et al., 1992; Meeuwisse et al., 2007). High-intensity load cycles are critical for optimal biological adaptations to prevent injuries, increase fitness and subsequently improve performance (Nunamaker et al., 1990; Reed et al., 2013; Soligard et al., 2016). However, greater distances of high-speed exercise have been associated with increased injury risk in Thoroughbred racehorses (Estberg et al., 1995; Verheyen et al., 2005; Cogger et al., 2006; Verheyen et al., 2006a; Verheyen et al., 2006b). With increasing speed, the force and torque applied to the limbs increase, meaning fewer load cycles are required to induce injury (Harrison et al., 2010; Martig et al., 2013; Martig et al., 2014).

In an early study of Thoroughbred racehorses in California, Estberg and colleagues (1995) used the frequency and distance of consecutive races and timed workouts to determine if excessive distances of high-speed exercise accumulated over a two-month sliding window contributed to fatal musculoskeletal injuries. This study reported that horses that accumulated greater cumulative racing speed distances, above cutoff distances estimated from the age matched control groups, were at higher risk of fatal musculoskeletal injury (Estberg et al., 1995). This was one of the earliest studies to support the hypothesis that musculoskeletal injuries may result from insidious damage caused by repeated loading during high-speed exercise which accumulates at a rate that exceeds the capacity for tissue to adapt or repair (Pool & Meagher, 1990; Estberg et al., 1995; Perkins, 2005). Examining exercise intensity over the preceding two months, provided a balance between temporality and obtaining a sample size large enough to assure adequate power to detect statistical significance (Estberg et al., 1995; Perkins, 2005).

In subsequent work by the same researchers, a case control study of Californian Thoroughbred racehorses examined exercise history over a nine-month period. Cases, identified retrospectively, had been euthanased due to catastrophic fracture and were compared with randomly selected control horses from the same race (Estberg et al., 1996a). The study investigated the relationship between exercise history and the risk of fatal skeletal injury sustained during racing. They reported a general association between excessive high-speed exercise and increased risk of fracture (Estberg et al., 1996a). More specifically, horses that accumulated greater than 35 furlongs of high-speed exercise in the preceding two months had a 3.9 (95% confidence interval (CI) 2.1–7.1) fold increase in risk of catastrophic fracture compared with horses that had accumulated 25 furlongs within the two-month period.

In a later study, Estberg and colleagues (1998a) assessed the association between exercise intensity and risk of injury using a retrospective case-crossover study. The average rate of distance accumulated was calculated using a sliding 60-day window and assigned a normal or excessive high-speed distance accumulated classification. Periods classified as excessive exceeded the 75th percentile and were followed by a 30-day hazard period. Exposed horses were those who sustained an injury in the hazard period and the remainder of the study population were considered non-exposed (Estberg et al., 1998a). They found that there was an increased risk of catastrophic musculoskeletal injury within 30-days of excessive accumulation of high-speed distance (Risk ratio: 4.2; 95% CI3.0-5.8) (Estberg et al., 1998a). However, given the understanding of bone remodeling, cases may have been unintentionally excluded due to the prescriptive definition of a hazard period. The influence of a longer hazard period was not investigated.

A cross-sectional study from California investigated the effects of racing-speed exercise on catastrophic suspensory apparatus failure and metacarpal condylar fracture in Thoroughbred racehorses (Hill et al., 2004). Analysis found several measures of exercise intensity were associated with an increased risk of injury (Parkin, 2008). More specifically, a longer interval since the last rest period (≥ 60-day period without a race or high-intensity training) and distance exercised in the month or months before the event were associated with an increased risk of injury (Hill et al., 2004). Moreover, the odds of metacarpal condylar fracture increased by 0.3% for every additional day since the last rest period. For the initial 120 days since the last rest period, the odds of suspensory apparatus failure remained constant, but thereafter increased three- to six-fold between 121 and 320 days (Hill et al., 2004). Additional distance (furlong) during high-intensity exercise, increased the odds of both suspensory apparatus failure and metacarpal condylar fracture by 4% (Hill et al., 2004).

Research from California utilised a retrospective case-control study to examine the relationship between high-speed exercise and catastrophic proximal sesamoid fractures in racing Thoroughbreds over a 3-year period from 1999 to 2002 (Anthenill et al., 2007). This study used official industry reports of career race and officially timed workouts to determine the number of workouts and races, and distance accumulated over different time periods. Horses that sustained catastrophic proximal sesamoid bone fractures had greater time in training and racing, increased high-intensity exercise in the previous 12 months and greater accumulation of high-speed distances (Anthenill et al., 2007). The use of retrospective records to quantify distances covered and time spent actively in training and racing has the potential to be a source of underestimation as a large proportion of high-speed exercise is performed during training and unofficial trials which was not recorded.

A prospective cohort study of racing Thoroughbreds in the United Kingdom was used to investigate training related risk factors for musculoskeletal injuries (Verheyen et al., 2006b). Daily training information was collected from a convenience sample of 13 racehorse trainers over a two-year period from 1998-2000, where training distances at canter (≤ 14 m/s) and gallop (> 14 m/s) were recorded. Cases were defined as any fracture diagnosed by a veterinarian and injury data was obtained through the trainers' veterinary surgeon. Results from the nested case-control study demonstrated that the risk of fracture was increased for horses that exceeded 44km (7700 bone loading cycles) of canter and 6km (880 bone loading cycles) of gallop within a 30-day period (Verheyen et al., 2006b). A subset of 335 study horses were followed from yearlings entering training; this group of previously untrained horses sustained 56 fractures (Verheyen et al., 2006b). Accumulation of canter exercise increased the risk of fracture, whereas accumulation of galloping had a protective effect, however, the risk of injury was increased when distances of cantering and galloping were increased within a 30-day period (Verheyen et al., 2006b).

A prospective cohort study was used to investigate risk factors for musculoskeletal injury in two-year-old Thoroughbred racehorses in Australia (Cogger et al., 2006). The authors found an association between musculoskeletal injury and the average distance trained at speeds ≥ 800 metres per minute as well as the percentage of high-intensity work days during the first preparation, noting a significant difference between trainers (Cogger et al., 2006).

Subsequent studies from Australia, investigating risk factors for fatalities in both flat and jump racing, found that Thoroughbred racehorses that accumulated high-speed exercise were predisposed to catastrophic injury in Thoroughbred racehorses (Boden et al., 2007). A case-control study investigating fatalities in flat racing found that distance of high-speed exercise accumulated in the 31-to-60-day period before the race start was most important in the risk of fatality (Boden et al., 2007). While an earlier study by the same team of authors identified that most cases of fatality were caused by musculoskeletal injury (Boden et al., 2006), a difference in the hazard period identified in studies from California determined a 30 day hazard period (Estberg et al., 1995; Estberg et al., 1996a; Estberg et al., 1998b) may be due to the broader case definition in this study (Boden et al., 2007; Parkin, 2008).

Conversely, some studies have found that increased cumulative high-intensity exercise decreased the risk of musculoskeletal injuries (Cohen et al., 2000a; Parkin et al., 2005; Perkins et al., 2005d). A case-control study performed in Kentucky found that horses that sustained musculoskeletal injuries during a race tended to have accumulated significantly fewer furlongs over the previous one or two months (Cohen et al., 2000a). In addition, no high-speed exercise accumulated in the one or two months prior to a race was associated with increased risk of injury, but not fatal injury (Cohen et al., 2000a). Lack of high-speed exercise in the month(s) preceding a race may have resulted from preexisting injury, hindering the horse's ability to race. Alternatively, lack of high-intensity exercise may have resulted in more porous bone and predisposed the horse to skeletal injury (Cohen et al., 2000a). Similarly, studies from the United Kingdom have found that horses doing no high-intensity exercise were at increased risk of distal limb fracture (Parkin et al., 2004b; Parkin et al., 2005). These results were likely due to the lack of adaptation of bone to loads experienced during racing, given that horses were not exposed to high-intensity exercise (Parkin et al., 2004b).

More recently, in human sport-science literature, the chronic:acute workload has been used to define the period most at risk of sustaining an injury (Gabbett et al., 2016). The aim is for workloads to be high enough to improve fitness, but not sufficiently high to risk injury (Gabbett et al., 2016). The chronic:acute workload describes the training load over the preceding week and compares this to the workload over the previous four weeks. A high acute to chronic workload ratio is indicative of the rapid increase in workload, which is associated with injury (Bourdon et al., 2017). Calculating the chronic:acute workload is particularly important to ensure safe resumption of exercise after a break.

This resonates with recent research from Australia, where authors found that more than half of the Thoroughbred racehorse training programmes quantified, involved high volumes of galloping which exceeded the previously reported level of risk for fractures (Morrice-West et al., 2020). The study utilised a cross-sectional study of 66 registered Thoroughbred racehorse trainers in Victoria, Australia. The study investigated training practices, including information on speeds and distances undertaken, as well as rest periods (Morrice-West et al., 2020). Despite the large difference in volume of galloping, race-day catastrophic musculoskeletal injuries were not significantly different in comparison with other racing jurisdictions (Boden et al., 2006; Morrice-West et al., 2020). The authors suggested that the risk of fracture may involve a complex relationship between training and racing loads (Holmes et al., 2014); raising the importance of transitioning horses from rest to race-level activity and how crucial specificity of workload is (Morrice-West et al., 2020).

The association between exercise volume and musculoskeletal injury is complex. This relationship involves a balance between the optimum amount of exercise required for functional adaptation without exceeding the physiological limits of the tissue (Verheyen et al., 2006b; Morrice-West et al., 2020). Differences in the association between high-intensity exercise and musculoskeletal injuries are due to a multitude of factors, including study design, geographical location, population of horses, management factors, outcome definitions, and methods to determine the outcomes (Crawford et al., 2020b).

1.11.5 Rest periods and interruptions to training

Rest periods are essential to reducing injury risk and enhancing performance during racing campaigns in Thoroughbred racehorses and in human athletes. Periods of rest and spelling are necessary in a training schedule to allow recovery and recuperation from the rigors of intensive exercise. However, inappropriate return to high-speed work has been associated with an increased risk of fracture, given that periods without intensive exercise result in de-adaptation of bone to high-speed galloping (Carrier et al., 1998; Riggs, 2002; Holmes et al., 2014). The complex relationship between exercise intensity and rest periods (van Ginneken, 2006) alludes to both training and racing practices playing a vital role in injury risk.

Loading during high-intensity training and racing can result in bone injuries due to the accumulation of damage and material fatigue of bone (Martig et al., 2014). It is well reported that increasing speed increases the load within the limbs (Martig et al., 2014; Morrice-West et al., 2020). Cyclic loading of bone that occurs during intense exercise, such as racing, results in bone fatigue (Holmes et al., 2014). Fatigue injuries occur when microdamage accumulates faster than can be repaired through remodelling (Martig et al., 2014). Microdamage, resulting from bone fatigue, that has accumulated during training and racing can be repaired through bone remodelling; rates of which are increased during periods of rest (Holmes et al., 2014; Martig et al., 2014; Whitton et al., 2018). Suppressed remodelling rates are considered to occur during periods of high-intensity work, linked to decreased porosity and minimal resorption surfaces that have been documented within distal metacarpal subchondral bone of horses in training (Boyde & Firth, 2005; Whitton et al., 2010; Whitton et al., 2013; Holmes et al., 2014). The combination of exposure to high repeated loading and low bone turnover exposes the bone to high risk of fatigue damage (Holmes et al., 2014). Periods of a suitable length without training, or exposure to high repeated loading, have beneficial effects on the bone remodelling where the fatigued bone that has accumulated during a racing campaign is replaced (Holmes et al., 2014; Morrice-West et al., 2021). In fact, the remodelling that occurs during rest has been found to be the most important intrinsic preventative process for stress factors in humans (Taylor et al., 2004; Morrice-West, 2020).

Research investigating subchondral bone microdamage in Thoroughbred racehorses suggested that reducing the intensity and duration of training and racing and/or increasing the length of rest periods would limit the risk of fatigue injury (Whitton et al., 2018). In this study, microcracks were identified in the subchondral bones from all 46 Thoroughbred racehorses that were examined; 26 horses were in training and 20 were resting from training at time of death. Microcrack density and microdamage grade were higher in older horses and microcrack density was higher in horses in training compared to with those resting from training. The accumulation of microdamage over time was greater than the rate of bone repair, however, the rate of microdamage removal increased during adequate periods of rest from training (Whitton et al., 2018). The authors of this study proposed that either periods of rest from training adequate to accelerate the removal of microdamage, or lower intensity training to reduce the accumulation rate of microdamage could be useful strategies for injury prevention. However, the optimal duration and timing of rest periods both within and between racing preparations has not been determined, due to the dynamic relationship between high-intensity work, low-intensity work and recovery.

The frequency and duration of rest periods depends on horse, trainer and environmental factors (Morrice-West et al., 2020). Data obtained in a cross-sectional survey of racing and training practices of Australian Thoroughbred racehorses, demonstrated that the decision making behind rest periods was mostly made for an individual horse, rather than a structured programme (Morrice-West et al., 2020). The group of trainers surveyed described the predominant reasons horses were rested and these included change in demeanour, reduced performance while racing or training, poor appetite, seasonal track surface preferences, preparation for future campaigns, recovery from physical fatigue and race scheduling/races available (Morrice-West et al., 2020).

A short rest period may increase the risk of injury if the length was sufficient for osteoclastic activity, where resorption has weakened the bone, and exercise recommences before deposition of replacement bone occurs during the osteoblastic phase. Conversely, while rest periods facilitate the repair of bone fatigue, prolonged periods of rest may result in de-adaptation with bone becoming more porous and less resistant to fatigue in response to a lower loading environment (Hernandez et al., 2006; Whitton et al., 2018). A retrospective case crossover study of Californian racehorses found a strong association between the risk of humeral fracture and the number of days after returning from a 60-day-plus rest period (Carrier et al., 1998). This study identified a hazard period of 10 days after returning from a 60-day rest period was most significant in terms of risk of fracture and hypothesised this relationship was due to incomplete remodelling (Carrier et al., 1998). However, the study did not account for potential confounders such as previous injuries or training history which may have been the reason for the horse entering the rest period to begin with (Sun, 2016). A case-control study of Thoroughbred racehorses in Florida investigated race-start characteristics associated with catastrophic musculoskeletal injury and found that horses that had more than 32 days since their last race start were 2.5 times more likely to sustain a catastrophic fracture comparted to horses with fewer than 14 days since their previous race (Hernandez et al., 2001). This study by Hernandez and colleagues (2001) also lacked information on the exercise history and pre-existing injuries which may have influenced the risk of injury.

More recently, a prospective cohort study of 535 two-year-old Thoroughbred racehorses with 26 trainers investigating risk factors for musculoskeletal injury across a 56-week period found that increasing the amount of rest prior to a training preparation, reduced the hazard of musculoskeletal injury (Crawford et al., 2021a). Periods without high-intensity exercise facilitate the repair of bone fatigue (Holmes et al., 2014), provided they are sufficiently long enough to ensure complete osteoblastic activity but not long enough that bone de-adapts to the reduced loading environment.

Mathematical modelling of adaptation of subchondral bone in Thoroughbred racehorses illustrated that during an under-loaded state, the rate of decrease in bone volume fraction was rapid in the initial 21-42 days (Hitchens et al., 2018). In the model, horses with a higher bone volume fraction and low bone specific surface available for remodelling took longer to reach homeostasis compared to horses starting resting at lower bone volumes (Hitchens et al., 2018). This suggests that horses that have undergone higher intensity training and racing schedules would have less benefit, in terms of bone turnover, from the same period of rest than horses with lower bone volume fraction (Hitchens et al., 2018).

Rest is critical for optimising not only health, but also performance during racing and training. A recent study, utilising data from trainer interviews regarding general stable practices for Victorian (Australia) Thoroughbreds, found that more rest periods, rather than longer rest periods, were associated with higher prizemoney earned per start (Morrice-West et al., 2021). Alternating rest periods with a higher number of shorter racing preparations in the early stages of training has been suggested to reduce the hazard of musculoskeletal injury; balancing sufficient stimulus to facilitate adaptation of bone and rest to enable tissue repair and minimise fatigue (Crawford et al., 2021a).

1.11.6 Early exercise

Determining the effects of early exercise on musculoskeletal health on the risk of injury and long-term benefits can be methodologically challenging, however, benefits of exercise on bone health have been documented in other animal models. For example, Warden and colleagues (2005) used an axial compression loading model to demonstrate that mechanical loading of mature rodent forelimbs, across a five-week period, enhanced the structural properties of bone and in turn, significantly improved fatigue resistance. Warden and colleagues (2007) then found that short-term exercise in immature rodents resulted in lifelong benefits to the structure of bone, bone strength, and fatigue resistance. The bone mineral content and density of the exercised ulnas was significantly different compared to nonexercised ulnas after a seven-week exercise programme (Warden et al., 2007). The rodent subjects were then restricted to a 92-week period of confinement and ulnas were removed after this detraining period (Warden et al., 2007). After detraining, ulnas exercised during growth had increased ultimate force, indicating improved bone strength, and a 10-fold greater fatigue life than non-exercised ulnas, despite increased brittleness (Warden et al., 2007). Further studies from the same authors, utilising high-resolution tomographic images, demonstrated the positive effects on bone mass (Warden et al., 2013).

The beneficial effects of early exercise are well documented in Thoroughbred racehorses and humans (Bass et al., 1998; Van Weeren et al., 2008; Firth et al., 2011). The musculoskeletal benefits of physical activity during childhood, particularly gains in bone mass, due to exercise, of which some are maintained in later life has been documented (Bass et al., 1998). Physiologically, the musculoskeletal system is most responsive during development (Firth et al., 2004a; Firth et al., 2004b; Perkins et al., 2004b; Rogers & Firth, 2004; Firth & Rogers, 2005; Firth et al., 2005; Rogers et al., 2008b, 2008a; Rogers et al., 2012b). In mature animals, appropriate application of load can enhance responses of bone and muscle tissue (Nunamaker et al., 1990; Boston & Nunamaker, 2000; Martig et al., 2014), however, tendon and articular cartilage do not demonstrate the same adaptive response to exercise after maturity (Birch et al., 1999; Brama et al., 2000a; Firth et al., 2004a; Smith & Goodship, 2008).

Several large-scale studies have demonstrated the benefits of early exercise on musculoskeletal health. The ‘EXOC’ research project, was designed to investigate the influence of exercise on musculoskeletal development as well as the occurrence of osteochondrosis (Van Weeren & Barneveld, 1999). At one week of age, the 43 Dutch Warmblood foals were randomly assigned to different rearing conditions: 14 foals received 24-hour stall confinement (3 metres by 3.5 metre box with mare), 14 foals received stall confinement but were subject to a training schedule, and 15 foals had free access to pasture 24 hours a day. The training schedule for the 14 foals on stall confinement with exercise consisted of exercise on six days of the week for a five-month period. The training regime involved a set number of sprints (range between 12 and 32 sprints) each day in a 48-metre-long enclosure. Foals were weaned at five months of age and eight from each group were randomly selected for euthanasia; the remaining foals were housed in a loose box with access to a small paddock until 11 months of age and were then euthanased (Cornelissen et al., 1999; Van Weeren & Barneveld, 1999).

Another large, intervention study (‘GEXA’) was established to investigate the effect of a conditioning exercise regime in addition to free exercise at pasture on musculoskeletal health in young Thoroughbreds in New Zealand (Rogers et al., 2008b). Thirty-three Thoroughbred foals were blocked for sex and sire and assigned to one of two groups: each group subject to a different exercise regime. The control group of foals (PASTEX) exercised spontaneously at pasture. The conditioned group (CONDEX) were raised on pasture as well as receiving a managed exercise programme from an average age of three weeks until they were broken in at 19-21 months of age. The conditioning exercise involved five days a week on a 515 metre grass and sand surface oval track over 1,030 metres in clockwise and anti-clockwise directions on alternate days, at a set base/velocity which increased as the foals were growing. The workload, as calculated using the Cumulative Workload Index, of the foals subjected to the exercise programme was 30% greater than the control group. At 18 months of age, six horses from each group were euthanased for post-mortem analysis and 20 entered the second phase of the study where they were broken in and trained for flat racing as two- and three-year-olds (Rogers et al., 2008b).

An early study, as part of the EXOC research, investigated the effects of exercise on bone mineral density in warmblood horses (Cornelissen et al., 1999). The bone density and cross-sectional area of the left third metacarpal bone and left medial proximal sesamoid bone were examined. The cross-sectional area of the metacarpus was significantly larger in the foals at pasture compared with those confined to a stall at five months of age, however, there was no difference in cross sectional area by the time the horses reached eleven months of age.

The bone parameters of the foals in the GEXA study were investigated through peripheral quantitative computed tomography undertaken at five different stages between four days and 17 months of age (Firth et al., 2011). In response to exercise, the mid-diaphysis of the proximal phalangeal and third metacarpal bone demonstrated greater resistance to deformation through increased bone mass, circumference and cortical thickness, which were significantly different between groups when pooled across all sampling ages (Firth et al., 2011). The increase in bone strength has been related to increased bone size and mineral content, rather than changes in volumetric bone mineral densities which were not significantly different between the two groups. This finding was supported, in part, by another study that used the same sampling population but investigated the response of bone to conditioning exercise in the radius and tibia of the horses (Nicholson & Firth, 2010). An increase in bone strength in the radius and tibia of horses exposed to conditioning exercise was observed (Nicholson & Firth, 2010). The increase in strength was attributed to the increased bone size and not necessarily bone mineral content as the tibia and radius responded differently in terms of changes to other bone parameters (Nicholson & Firth, 2010). The differences suggest that each bone responds to its loading environment in a different manner, depending on the bone’s shape, location, function, and architecture (Nicholson & Firth, 2010). The application of load, above ‘normal’ activity, during growth did not have negative effects on bone (Rogers et al., 2008b). Potential pathological changes including osteochondrosis lesions and bone density gradient, were noted in areas of high loading in both exercised and non-exercised groups suggesting their presence was not affected by the application of exercise (Firth et al., 2009; Kawcak et al., 2010). Both studies concluded that there were no adverse effects of the early conditioning programme on bone and demonstrate the benefit of increasing the resistance of bones to deformation.

A lack of negative effects of early conditioning exercise on cartilage health have been found. At 18 months of age, chondrocyte viability and the quality of articular cartilage was superior in the horses that had undertaken an exercise regime (Dykgraaf et al., 2008). Exercised horses had significantly greater mean percentage of viable chondrocytes (14% greater) than the control group (Dykgraaf et al., 2008).

Moreover, maturation of the cartilage extracellular matrix was more advanced in horses that had been exposed to the conditioning exercise (Van Weeren et al., 2008). Detailed analysis of the layers of articular cartilage from the surface down to the calcified cartilage, demonstrated an advancement in the development of cartilage in the CONDEX group (Nugent et al., 2004; Kawcak et al., 2010), supported by the findings of higher levels of hydroxylysine, hydroxylysylpyridinoline cross-links and pentosidine cross-links in the CONDEX group compared with the PASTEX group (Van Weeren et al., 2008). Cartilage defects, ranging from subtle changes through to severe disruption, were noted in most horses, particularly in the PASTEX group, however, the study had low statistical power to detect a significant difference between the two groups (Kim et al., 2009). The cartilage defects noted were considered to be unimportant preclinical lesions as none were associated with lameness, injury or osteoarthritic changes (Kim et al., 2009).

The EXOC study demonstrated the importance of biomechanical loading during growth for the development of articular cartilage (Brama et al., 2002). Articular cartilage, at birth, is relatively isotropic and undergoes structural and functional reorganisation as the tissue matures (Mienaltowski et al., 2008; Rieppo et al., 2008). While metabolism of cartilage is active during growth, it has been well established that articular cartilage has a low turnover rate in mature animals (100-200 years) (Maroudas et al., 1992; Verzijl et al., 2000). Therefore, the ultimate biomechanical characteristics of articular cartilage are influenced by the loading endured in immature animals (Brama et al., 2000a; Brama et al., 2002; Hyttinen et al., 2009). The adaptation of the tissue is site specific and associated with the biomechanical demands, where areas that receive constant low-level loading during weight-bearing have greater amounts of glycosaminoglycan and proteoglycan, providing resistance to compressive stresses (Brama et al., 2000a; Brama et al., 2000b; Mienaltowski et al., 2008). In comparison, areas that receive intermittent high stress loading have high levels of collagen for tensile strength (Brama et al., 2000a; Brama et al., 2000b; Mienaltowski et al., 2008; Gannon et al., 2015). Cartilage is most adaptive during postnatal maturation (Van den Hoogen et al., 1999). Foals exposed to exercise demonstrated developed topographical heterogeneity of the extracellular matrix, unlike those that were confined. Moreover, by five months of age, differences in collagen and hydroxylysine had developed in both exercised groups but not the group of foals deprived of exercise (Brama et al., 2002). Where foals were deprived of exercise during the first five months, articular cartilage failed to fully develop the characteristics of maturation. Moreover, a six-month period allowing the exercise-restricted foals to re-establish moderate levels of activity was ineffective in promoting compensatory articular cartilage adaptation (Brama et al., 2002; Brommer et al., 2005). These results demonstrate the importance of biomechanical loading at a young age to ensure tissue is adapted to withstand loading conditions encountered later in life, and ultimately provide protection from injury. In a study on young beagle dogs, moderate levels of loading were associated with increased glycosaminoglycan production (Kiviranta et al., 1988), however, strenuous exercise led to depletion of glycosaminoglycan in high-loaded areas (Kiviranta et al., 1992; Arokoski et al., 1993).

Despite the foals that were confined but subject to short bouts of high-intensity exercise demonstrating benefits from the short bouts of exercise, deleterious effects on various tissues were reported (Barneveld & Van Weeren, 1999). For example, chondrocytes harvested from this group at 11 months could not be stimulated to increase metabolic activity, which contrasted from the other two groups (Van den Hoogen et al., 1999). The combination of a sedentary lifestyle and high-intensity exercise during growth caused detrimental effects; possibly due to overstimulation (Van den Hoogen et al., 1999). However, this study did not include a group of foals that were kept at pasture and provided controlled high-intensity exercise, to make direct comparisons with (Rogers et al., 2008b).

Similarly, early exercise induces positive adaptative responses from tendons. At birth, the tendon is homogenous and functionally unadapted (Smith et al., 2002). Tendons undergo a raft of changes during growth, including: maturation of the intrafibrillar cross-links; fibril diameter increase; increased concentration of collagen; and increased concentration of cartilage oligomeric matrix protein (Parry et al., 1978; Gillis et al., 1997; Patterson-Kane et al., 1997; Smith et al., 1997). The changes ultimately lead to an increase in tendon stiffness during maturation (Gillis et al., 1997). Responses to exercise and the mechanical forces imposed during growth, result in an increase in tendon volume and cross-sectional area (Firth et al., 2004a; Perkins et al., 2004b). The adaptation of the tissue is site specific and associated with biomechanical demands (Vogel & Heinegård, 1985; Vogel & Evanko, 1987). However, tendon synthesis ceases, and the adaptive ability of the tendon is significantly reduced at skeletal maturity (Smith et al., 2002). Although exercise has been found to optimise tissue adaptation (Cherdchutham et al., 2001), once the tendon structure is mature, repeated load cycles encountered with increasing age and exercise result in gradual structural deterioration of the tendon (Parry et al., 1978; Gillis et al., 1997; Patterson-Kane et al., 1997; Smith et al., 1997; Addis & Lawson, 2010).

The effects of exercise on the biomechanical properties of the superficial digital flexor tendon have been explored in horses (Cherdchutham et al., 2001). In the EXOC study, the cross-sectional area of the superficial digital flexor tendon and the normalised force at rupture were significantly higher in foals that had free access to pasture compared to both the confined and confined with controlled exercise groups at five months of age (Cherdchutham et al., 2001). Moreover, at five months of age the group of foals kept on pasture had lower stress at 4% strain, indicating the tendon tissue was less stiff compared to the other groups (Cherdchutham et al., 2001). However, at 11 months of age, after all remaining foals had been housed together with access to physical activity, there were no significant differences in the cross-sectional area nor the normalised force at rupture of the superficial digital flexor tendon. The force at rupture in the non-exercised group increased significantly, while the force at rupture in the pastured group decreased (Cherdchutham et al., 2001). The development of collagen structure in the confined and box trained groups still lagged behind that of the pasture group indicating that the sedentary lifestyle at the time when the tissue is most adaptive may have a long-term negative impact on tendons (Cherdchutham et al., 1999). The study also found that the group of foals that were box trained experienced reduced tenocyte functionality demonstrating that both a lack of exercise and excess exercise in growing horses can impair tendon composition and subsequent functionality (Cherdchutham et al., 1999; Cherdchutham et al., 2001).

The GEXA study found that conditioning exercise did not have negative effects in tendons. At 18 months of age, there was no difference in the cross-sectional area of the superficial digital flexor tendon between the two groups (Moffat et al., 2008). This study found the greatest increase in mean cross-sectional area occurred between the ages of five and eight months with no evidence of tendonopathy in either group. The study failed to find evidence of structural adaptive hypertrophy of the superficial digital flexor tendon either due to the exercise regime not being sufficiently demanding to induce a response, or because the free exercise undertaken at pasture was sufficient to induce maximal adaptation of tendon.

There is a preponderance of evidence that musculoskeletal tissues adapt to mechanical load during growth and development (Brama et al., 2002; Warden et al., 2007; Rogers et al., 2012b; Warden et al., 2014). In Thoroughbred racehorses, evidence supports that early exercise induces positive adaptive responses of tissues. Foals subjected to exercise with free access to pasture demonstrated superior conditioning of their musculoskeletal system. However, despite the strong support for early exercise from the literature, the maturity of racehorses, and the appropriate age to introduce Thoroughbreds to race training, remain controversial topics (Rogers et al., 2021).

Whilst the response of tissues to a conditioning programme during growth have been described in Thoroughbred horses, there is scant information on industry practices and management of young greyhounds. There are industry constraints regarding the size of kennels and whelping areas (Greyhound Racing New Zealand, 2023a), however, the minimum size requirements of these facilities would be well below an area suitable to allow galloping and strengthening of tissues.

1.11.7 Age started racing

The protective effect of early exercise on risk of injury may extend to the early onset of racing training. There is evidence that horses that started their racing career as two-year-olds had more successful racing careers, in terms of being more likely to win or place in a race as well as having higher earnings, had more racing starts, and raced for a longer period than horses that started racing at an older age (Bailey et al., 1999; Tanner et al., 2012; Tanner et al., 2013; Velie et al., 2013a).

Despite biological evidence demonstrating superior response of tissues to horses provided with exercise during growth, there have been conflicting results when age at first start has been analysed as a risk factor for musculoskeletal injury. Studies have found that horses commencing racing at an older age were at higher risk of distal limb fracture (Rosanowski et al., 2017b) and catastrophic musculoskeletal injury (Georgopoulos & Parkin, 2016) compared with horses starting at a younger age. Another study found that two-year-olds starting racing had a lower risk of fatal lateral condylar fracture compared to three- and four-year-old starters, however, there was no statistical difference between two-year-old starters and horses that started racing at age five years or more (Parkin et al., 2005). Parkin and colleagues (2005) suggested that horses that did not race as two-year-olds were unlikely to have accumulated the same amount of time in training and the resultant lack of musculoskeletal adaptation in horses that had a delayed start to racing could result in injury. The authors also addressed the idea that horses that failed to race as two-year-olds may have been the result of subclinical injury sustained before or during training (Parkin et al., 2005). Similarly, the delayed age at first race could be due to trainers not making the most of the ability of the musculoskeletal system to adapt to the stressors experienced in training and racing, however, encouraging trainers to start exercise at a younger age may have unexpected and detrimental consequences (Hitchens et al., 2019) if workload and management factors are not moderated or well managed (Rogers et al., 2012b; Rogers et al., 2020).

In contrast, other studies have found no association between age at first start and risk of musculoskeletal injury suggesting that the relationship between these factors is not simple. Estberg and colleagues (1998a) found no difference in risk when comparing horses that started racing as two-year-olds compared to three-year-olds, and Boden et al. (2007) found a similar lack of association when comparing injuries in two-year-olds with horses three years and older. There are a number of factors that could be influencing the results, particularly the use of retrospective study designs where little was known about extended exercise history and management during growth in these studies. Despite some research not finding an association between age at first racing start and risk of musculoskeletal injury, performance measures have proved a beneficial relationship (Tanner et al., 2011; Tanner et al., 2012; Tanner et al., 2013).

Other studies have reported a higher incidence of injury in two-year-old horses compared to older horses (Crawford et al., 2020b). Despite the higher incidence of injury in two-year-old horses, compared with older horses, they were more likely to race or trial again following injury (Crawford et al., 2020b). These horses typically sustain different types of injuries compared with their older counterparts. The observed increase in incidence of musculoskeletal injury in two-year-old racehorses, particularly the prevalence of dorsal metacarpal disease, is likely due to the commencement of training and naïve tissue responding to loading, rather than age (Nunamaker et al., 1990; Perkins et al., 2005b; Verheyen et al., 2005; Cogger et al., 2008a; Rogers et al., 2020). This is supported by the increase in incidence of dorsal metacarpal disease noted in three- and four-year-olds commencing training (Nunamaker et al., 1990). Exercise regimes can be adjusted to prevent the incidence of dorsal metacarpal disease (Verheyen et al., 2005). Dorsal metacarpal disease has also been noted in racing greyhounds when commencing training (Davis, 1971), however, no research has demonstrated the effects of age when commencing racing in racing greyhounds.

As well as the hypothesised protection of the musculoskeletal system, early exercise in greyhounds may provide performance benefits when commencing racing at a younger age. Greyhounds are precocious animals and have been demonstrated to reach peak speed at the age of 2.4 years, with performance declining thereafter (Täubert et al., 2007). Early exercise would not only provide the strength and speed training, but also aid in educating the greyhounds in track etiquette. Greyhounds are reported to be skeletally mature at 14 months of age (Smith, 1960), so introduction to exercise and training before this age would be important for musculoskeletal health. The age at which greyhounds can commence racing is constrained by the industry; the GRNZ Rules of Racing, at the time of this review, state that greyhounds must be 16 months of age to commence their racing career (Greyhound Racing New Zealand, 2017).

1.11.8 Genetics

Wastage of racing animals is of international concern (Jeffcott et al., 1982; Heleski et al., 2020; Mactaggart et al., 2021; Flash et al., 2022b). Informed and selective breeding decisions may help to reduce musculoskeletal injuries in racing animals. Improved performance traits, including speed and rank (winnings and placings), seen in the greyhound population over time have been attributed to generations of selective breeding (Dockerty, 2017), which some authors have questioned as extreme selection bias (Schneider et al., 2012). However, selection of performance traits may, in part, be countered by antagonistic selection on injury risk (Sharman & Wilson, 2023). It is common, in the racing industry, to breed from animals that have retired due to serious injury, enabling the animal to maintain some economic purpose (Dockerty, 2017). However, this practice may inadvertently be selecting greyhounds that are more prone to injury, rather than targeted selection based on genetic merit (Dockerty, 2017).

Selective breeding for particular traits has the risk of reducing genetic diversity of the population (Lacy, 1997). Racing Thoroughbreds provide an example of a large, closed population of animals, where all Thoroughbreds can be traced back to three paternal lines (Cunningham et al., 2001; Todd et al., 2018). The elite athleticism of the breed is, in part, a result of more than 300 years of breeding practices (Gu et al., 2009; Petersen et al., 2013), however, this has resulted in reduced genetic diversity due to high levels of inbreeding (Cunningham et al., 2001; Todd et al., 2018). Thoroughbred racehorses appear to have a lower mutational load than expected, and recent studies have attributed this to effective purging through negative selection on phenotypes which may have improved racing performance over time (Todd et al., 2018; Orlando & Librado, 2019; McGivney et al., 2020).

1.11.9 Trainer

Epidemiological studies in Thoroughbred racehorses have consistently identified a trainer effect associated with fractures and soft-tissue injuries (Verheyen & Wood, 2004; Perkins et al., 2005d; Cogger et al., 2008a; Rosanowski et al., 2017a). Trainers' ability to provide an appropriate balance between load and recovery has been attributed as the reason for the significant difference in injury rates between trainers (Rogers et al., 2020). It is likely that some trainers have a greater ability to detect injuries at an earlier stage and employ tactics to prevent injuries occurring or worsening (Rogers et al., 2020). For racing greyhounds, the influence of the trainer on musculoskeletal injuries is likely due to a number of environmental factors, including but not limited to the exercise and training regime, housing and kennel provisions, training facilities (length, surface, type of training facilities), racing schedules and level of veterinary involvement. Trainer was included as a random effect in the mixed-effects logistic regression model of injury and fatality risk in New Zealand racing greyhounds, however, was found to have negligible effect (Stevenson et al., 2009).

1.11.10 Track geometry / location of racetrack

Studies investigating injuries in racing greyhounds have identified differences in the incidence and types of injuries sustained at different racetracks (Hickman, 1975; Sicard et al., 1999; Iddon et al., 2014). A study of orthopaedic injuries at five

Wisconsin tracks observed a higher injury rate at an oval track with shorter straights and a tighter radius in the bend (Sicard et al., 1999), however, the small number of tracks sampled and a number of potential confounding factors must be considered. Another limitation of this study was the analysis of all musculoskeletal injuries together, rather than looking at different types of injury. A study of injuries at three tracks across the North Island of New Zealand identified a difference in incidence rates between the tracks (Stevenson et al., 2009). Although there was a difference in the odds of injuries reported between tracks, no conclusions were drawn regarding differences in track design (Stevenson et al., 2009). More recently, investigation into serious tarsal injuries at tracks in Victoria, Australia, reported a lack of association between racetrack design and risk of injury (Beer, 2014). Tracks which reported significantly lower odds of tarsal injury varied in design of track circumference, bend radius and width of track; there were no unique features of the track that had a higher odds of serious tarsal injury (Beer, 2014). Moreover, the track that had the highest risk of injury and the track with significantly lower risk were of similar design, suggesting other factors were involved (Beer, 2014). Increased forces endured on the limbs while travelling around a bend are well documented in greyhound injury literature and it is likely that travelling around a bend is the main contributing factor for tarsal injuries rather than astute changes in track design.

One means of assessing the influence that tracks have upon racing injuries is to compare data before and after renovations and/or remedial work. The injury rate at one of the tracks captured in the study by Stevenson and colleagues (2009) decreased from 29.1 (95% CI 25.3-33.2) injuries per 1,000 starts to 21.2 (95% CI 16.7-26.6) injuries per 1,000 starts after renovations to the track. While there is a notable improvement, the difference in sample sizes accounted for the wider confidence interval. Before renovations, during the 44-month period from 21 July 2003 to 21 March 2007 there were 209 injuries reported across 7,183 racing starts. The racetrack was closed for four months and data from 20 August 2007 to 25 June 2008 were included in post-renovation analysis. Across the seven-month post-renovation period, there were 74 injuries from the 3,489 racing starts which was a noticeable increase in the number of racing starts (Stevenson et al., 2009). It is unclear if the increase in racing starts was an increase in frequency of racing within the existing population, or if there was a dramatic increase in the racing population over this period. Moreover, there was no information provided as to whether the renovations involved scheduled maintenance or substantial alterations to the track.

An overwhelming amount of evidence indicates the majority of injuries occur on the bends of the racetrack (Bloomberg & Dugger, 1998; Auer, 1999; Sicard et al., 1999). While Sicard and colleagues (1999) found that nearly half (858/1,887; 45.5%) of the injuries occurred at an unknown location on the track, they found that 20% of injuries occurred at the first turn and a total of 36.9% of injuries occurred on one of the turns throughout the race (Sicard et al., 1999). Results from two surveys monitoring injuries at six tracks between 1984 and 1990, and 16 tracks from 1990-1995, in Florida, USA, found a much higher rate of injuries occurred on the bends (Bloomberg & Dugger, 1998). This research reported three quarters of the racing injuries occurred on the bends, where more than half (471/830; 56.7%) of injuries sustained during a 5/16-mile race occurred at the first bend and 18.4% (153/830) at the second bend (Bloomberg & Dugger, 1998). A study examining injuries at six racing tracks in South East Queensland, Australia, across just over a 12-month period (17 September 1997 – 6 October 1998) found 80% of injuries occurring on the bend; 65% of injuries occurring at the first turn and 15% at the second turn (Auer, 1999). In this study, there was no report difference in the proportion of greyhounds injured on the first bend between sand and grass tracks (Auer, 1999). The higher number of injuries sustained on the bends indicates that the geometry of the track is a contributor to the risk of injury.

A study from Australia, investigating galloping gait characteristics across five tracks with different specifications, noted greyhounds had a more consistent stride magnitude on a semi-circular track that had no sudden transitions from straight to bend, and abrupt changes in accelerations at two oval tracks as the greyhounds entered the bend (Hayati et al., 2019b). Previous studies have theorised that greyhounds adopt two different strategies in attempt to reduce excessive centrifugal force while entering and galloping around the bend. One strategy is that greyhounds reduce their speed and this is a contributing factor to the congestion and resulting interference that occurs on the bend (Ireland, 1998). The other strategy is they alter their running path to seek a greater radius which reduces the centrifugal force (Ireland, 1998). Both mechanisms would contribute to interference, and the resulting change in acceleration, while entering the bend. More recently, research established that, unlike Thoroughbreds and human athletes, greyhounds do not reduce their speed nor foot-contact timing while entering a tight bend and withstand dramatic (65%) increases in limb forces while rounding a bend (Usherwood & Wilson, 2005). The lack of reduction in speed while entering and travelling around a bend is inconsistent with findings from other research which demonstrate that stride-length reduced while stride frequencies were similar while travelling around a bend (Hayati et al., 2017a; Hayati et al., 2019b). The conflicting results could be due to differences in the degree of banking or radius of the turn of the tracks, given that this information was not readily available. There is also a possibility that the positioning of the lure impacted the greyhounds running path around the bend. Usherwood & Wilson (2005) in the United Kingdom note that the lure was located on the outside of the track, for most racing, whereas the research by Hayati and colleagues was conducted in Australia where the lure is typically driven around the inside of the racetrack. Positioning of the lure could influence the path the greyhounds follow around the bend, however, research comparing the positioning of the lure with the incidence of musculoskeletal injury has not been conducted.

The geometry and design of the racetrack influences the path in which the greyhounds run. The design of the bend has been reported to impact on the risk of collisions occurring while approaching and entering the bend (Hayati, 2019). Where the transition between the straight and the bend is abrupt, greyhounds are more likely to lose co-ordination or change their running path (Mahdavi et al., 2018; Hossain et al., 2020). A study from Australia reported that approximately 80% of catastrophic and major injuries were caused by congestion (Eager et al., 2017), involving checking and colliding between greyhounds (Poulter, 1991). Interference is common during a race, occurring in up to 80% of races (Bloomberg & Dugger, 1998), affecting the stride and in turn altering the load distribution on the limbs (Guilliard, 2013).

No two racetracks are ever the same; idiosyncrasies exist due to environmental differences and geographical constraints (Mahaffey et al., 2012; Rogers et al., 2014). The considerable variation in track design, including length and width of straights and bends, bend angles, the level of banking and construction of the surface influence the forces endured by the greyhounds and play an important role in the differing injury rates (Hossain et al., 2020). Engineering concepts have been used to aid the conceptualisation of an 'ideal' curvature for racetracks (Eager et al., 2016) and identified that a smoother running path, as facilitated by transitional curves, is recommended as they help to reduce disturbances in gait symmetry (Fredricson et al., 1975; Hossain et al., 2020). Another important aspect of track geometry is the radius of the bend. Increasing the radius of the bend will decrease the centrifugal force and reduce the risk of injury (Fredricson et al., 1975; Mahdavi et al., 2018). Furthermore, the level of banking is another way of reducing centrifugal force acting on the greyhound as it travels around the bend (Fredricson et al., 1975). The desired level of banking is directly proportional to the radius of the bend and the speed at which the greyhound is travelling (Fredricson et al., 1975), and thus will differ between tracks. A study investigating the effect of increased banking on injury rate in Standardbred horses found that a 0.9 degree increase (4.8 to 5.7 degrees) in banking on the bend resulted in a 22% decrease in injuries (Evans & Walsh, 1997). Although the post-renovation degree of banking was still less that optimal for the radius of the bend, there was a significant reduction in injuries from 8.5 to 6.6 per 1,000 racing starts (Evans & Walsh, 1997). There are limitations to improving track design, where the size of the radius is often dictated by real-estate constraints and the level of banking can encounter maintenance issues (for example drainage and maintaining the camber across the track). Nevertheless, research has demonstrated the effects of track design on injuries and where these optimal designs are not met, improvements must be made to reduce the risk of greyhounds sustaining an injury.

An early review of the design of Thoroughbred racetracks, highlighted the merits of a straight track in reducing the problems associated with racing around bends (Fredricson et al., 1975). While this review identified that using straight tracks would eliminate some of the injuries that arise due to transitions between the straight and bend, and poorly designed bends, it recognised the main issue of straight tracks would be the impaired spectator views of much of the race. Straight tracks would also reduce racing greyhound injuries. In 2023, the spectator concerns are relatively invalid, given improved technology for screening the races live, availability of and popularity of online and/or offsite wagering, and the reduction in patrons attending races as the acceptance of greyhound racing as a spectator sport decreases (Hampton et al., 2020). At the very least, a straight track would eliminate all injuries associated with running around a bend (Eager et al., 2017). This has been documented in a study from Victoria, Australia, which found that the lowest odds of serious tarsal injury occurred at the only straight track in the study compared with the reference, oval track (Beer, 2014).

Moreover, reports from raw empirical data and anecdotal observations detail that there are fewer serious and catastrophic injuries sustained during racing on a straight track compared to an oval track. To my knowledge, there are no published peer reviewed articles that detail injury rates or risk factors for injuries on straight tracks.

While track design is an important concept, a number of confounding factors make interpretations of the track geometry as a risk factor for musculoskeletal injury troublesome; in particular, environmental, industry, and biological factors. Differences in climate, track conditions, and availability of races and training due to the geographic location of the racetrack have been considered risk-factors for musculoskeletal injuries in racehorses (Parkin et al., 2004a; Perkins et al., 2005b; Boden et al., 2006). Climatic effects, such as rainfall and ambient temperature, can influence the material properties of the track surface, the condition (going) of the track and the maintenance required (Mahaffey et al., 2012). A study which investigated racing injuries at two greyhound tracks in the United Kingdom found that injury rates sequentially increased as the going of the track increased (became faster) and there was a significant difference in injury rates between the track ratings (Iddon et al., 2014). This is supported by numerous studies in Thoroughbred racehorses which have identified a lower risk of musculoskeletal injury on slower tracks ("slow", "heavy" or "dead" rating) compared with faster tracks ("good", "fast" or "firm" rating) (Parkin et al., 2004a; Boden et al., 2007; Rosanowski et al., 2016; Bolwell et al., 2017).

The pattern of racing and distribution of trainers across the country may influence injury rates at different racetracks. At a racecourse level, the number of days since the last race meeting has been associated with fracture risk in Thoroughbred racehorses in the United Kingdom, where fewer days since the previous race meeting was significantly associated with an increased odds of fracture (Parkin et al., 2004a). The authors hypothesised that this may be due to reduced time available for repair and maintenance of the turf and all-weather track surfaces (Parkin et al., 2004a). In New Zealand, the opportunity to race has remained relatively consistent for Thoroughbred racing in New Zealand between 2005 and 2018, although a 2% decrease per season in the number of races has been noted since the 2008/2009 racing season which matched the 2% decrease in number of horses with a race start per season (Bolwell et al., 2014a; Legg et al., 2021). The proportion of horses based in each region (Northern, Central and Southern) was consistent with the racing opportunities for the respective region

(Bolwell et al., 2014a) and it has been noted that most horses race in the same region they are trained in, with a small number travelling greater distances to premier race meetings (Bolwell et al., 2014a; Rosanowski et al., 2014). The influence of trainer on musculoskeletal injuries has been reported as a risk factor in Thoroughbred racehorses (Cogger et al., 2006). Previous studies have also identified differences in the trainer's justifications for entering horses in races as well as differences in patterns of training between different regions (Perkins et al., 2004a, 2005a; Bolwell et al., 2010), indicating other factors could be influencing the injury rate at different racetracks. The geographical spread of greyhound trainers across New Zealand was reported in Stevenson et al. (2009) and demonstrated that more trainers were, in general, located close to racetracks. To my knowledge, there is currently no published information about the opportunities for racing greyhounds to race.

Another regional effect that may occur between racetracks is the difference in personnel working at the racetracks. Perkins and colleagues (2004a), considered that the detection of injuries may differ between regions. While not necessarily an issue for the serious and catastrophic musculoskeletal injuries, the different personnel working at tracks, including Stipendiary Stewards, racing officials and veterinarians, may vary in opinion on what warrants further veterinary analysis on race day and therefore influence the number of injuries being recorded.

The position of the mechanical lure on the racetrack has been considered a contributing factor to racing collisions and the resulting injuries sustained (Mahdavi et al., 2018). Analysis of data obtained across two years from three tracks in New South Wales, Australia, demonstrated that there was a reduction in the incidence of injuries for a longer lure arm compared with a shorter arm (Mahdavi et al., 2018). A longer lure arm positions the lure further into the track with the theory that sight of the lure is not as obscured for the field, resulting in a smoother running path and reduction of collisions (Eager et al., 2017; Eager et al., 2018). This has been demonstrated through a decreased greyhound yaw rate (rate of change of heading) with increasing lure arm length (Mahdavi et al., 2018). A lure that is closer to the rail, or a poorly designed racetrack (lack of transition into bend) may result in greyhounds running to a larger radius in order to maintain vision of the mechanical lure while turning (Hayati et al., 2019b). In the United Kingdom and Ireland, the lure is positioned on the outside of the racetrack (compared with the lure on the inside of oval tracks in New Zealand and

Australia) and there is no peer reviewed literature that analyses the running path of greyhounds in the United Kingdom and Ireland. It would be interesting to see if there was a difference in path trajectories between the two.

Numerical modelling of greyhound kinematics, along with comparison to actual race data, have demonstrated that the distance of the lure in front of the field, along with the motion of the lure are important factors in reducing congestion of greyhounds during the race (Hossain et al., 2019), again, highlighting how different personnel in different regions may influence the incidence of injuries at different racetracks.

1.11.11 Race distance

In a survey of five greyhound racing tracks in Wisconsin, United States of America, certain race distances had a significantly higher rate of injury than others. The incidence of injury occurring over 7/16 mile (704 metre) and 3/16 mile (302 metre) races was greater than the incidence over 5/16 mile (503 metre) and 3/8 mile (604 metre) races (Sicard et al., 1999). Stevenson and colleagues (2009) also noted a higher incidence of injury in 200–300 metre races and 500–600 metre races compared to the other distances (300–400 metre, 400–500 metre, 600–700 metre and 700–800 metre). Conversely, Beer (2014) found no relationship between serious tarsal injury and race distance. Given differing track geometries and other track properties, it is likely there are a number of factors influencing injury rate when data across several tracks are pooled for analysis.

The relationship between race distance and injuries has been noted several times in the Thoroughbred literature. Horses competing in longer races have been found to be at a higher risk of musculoskeletal injury (Bailey et al., 1998; Parkin et al., 2004a; Boden et al., 2007). One study of Thoroughbred racehorses in Victoria, Australia, reported 1.5 times increase in the odds of fatality with every additional one kilometre of race distance (Odds ratio (OR) 1.45; 95% CI 1.05 – 2.01) (Boden et al., 2007). Parkin and colleagues (2004) proposed the increased risk in longer races may be due to greater exposure time at risk, an increased number of load cycles and the possibility of more fatigued horses (Parkin et al., 2004a; Boden et al., 2007). It has been confirmed that Thoroughbred racehorses racing over greater distances are also trained over greater distances, accruing higher number of load cycles and bone fatigue compared to horses racing at shorter distances (Morrice-West et al., 2020; Morrice-West et al., 2021). Despite total bone fatigue accumulation increasing with increasing race distance, this does not occur at a proportional rate (Morrice-West et al., 2020; Morrice-West et al., 2021; Morrice-West et al., 2022). Both the number of strides per 200 metres and the mean speed reduce with increasing race distance (Morrice-West et al., 2021; Morrice-West et al., 2022). Speed profiles across different racing distances have been calculated in a recent study of greyhounds in Australia (Eager et al., 2021). After the initial rapid increase to peak speed in the first 80-150 metres of the race, speed gradually decreases for the remainder of the race (Eager et al., 2021). The lack of clear association between increasing race distance and risk of injury in racing greyhounds may be due to the shorter distances travelled and less variation in race distances (295–779 metres) compared to Thoroughbred racehorses.

1.11.12 Track surface

As with the design of the track playing a critical role in reducing injuries, traits of racing surface, including material, moisture content and surface maintenance are important contributing factors (Symons et al., 2016). There is evidence of an association between different track surfaces and racing injuries (Poulter, 1991; Iddon et al., 2014). Not only do track surfaces influence the incidence of injuries, but different types of injuries are seen on different racing surfaces (Prole, 1976; Poulter, 1991; Auer, 1999). Results from a report from South East Australia found that the total incidence of injuries was similar on grass (12.06 injuries per 1,000 starts) and sand (11.59 injuries per 1,000 starts) surfaces (Auer, 1999). However, more serious appendicular fractures (for example tarsal fractures) were more commonly sustained on sand tracks compared with grass tracks. Whereas, the proportion of tendon and ligament injuries, in particular toe collateral ligaments ruptures, were greater on grass tracks compared to sand tracks (Auer, 1999). The optimal racing surface protects the foot during contact with the track by absorbing the forces of impact, and at the same time, provide enough traction for controlled running (Gillette, 2007; Hayati et al., 2020).

The composition of the track materials, moisture content and compaction traits of the surface alter the mechanical properties of the surface and contribute to the safety of a racing surface (Ratzlaff et al., 1997; Ireland, 1998; Symons et al., 2016; Hayati, 2019). These factors influence track firmness and, although firmer surfaces may improve desired performance parameters (reduced race times), a significant increase in the injury rate on fast tracks compared to slower tracks has been noted (Iddon et al., 2014). Differences in surface compliance and the risk of musculoskeletal injuries are likely due to the differing impact forces. Moreover, repeated exposure to high-intensity loading and the impact shock encountered on a firm track increase the propensity of cyclic overload injuries (Holt et al., 2014). On the other hand, a softer, lower density surface may reduce locomotion efficiency and impact running performance due to increased muscular effort required for propulsion (Crevier-Denoix et al., 2010; Holt et al., 2014). A study investigating the effects of surface compliance on galloping dynamics in racing greyhounds, found that the forces acting on the hind leg were substantially greater on a relatively hard natural grass surface compared with a relatively soft synthetic surface (Hayati et al., 2019a) supporting the high rate of hock fractures reported in the literature (Sicard et al., 1999; Iddon et al., 2014). In New Zealand, all greyhound racing is conducted on a sand surface. Research conducted in Australia has concluded that a relatively wet sand (moisture level 20%) with a low density (1.35g/cm^3) provided the most favourable surface for both race performance and injury reduction in greyhounds (Hayati et al., 2020).

Regardless of the surface substrate, preparation and maintenance of the track surface are essential to maintain a consistent surface. Analysis of sand surface condition across a one-year period from July 2019 to July 2020, specifically looking at moisture content and firmness information, demonstrated that inconsistencies in surface condition, namely high fluctuations in data obtained from the inside and middle of the track, can contribute to catastrophic injuries (Hayati et al., 2020). Moreover, inconsistencies in track surface result in varying forces which has been demonstrated in Thoroughbred horses where hoof impact forces over previous hoof indentations were higher than on a harrowed surface (Kai et al., 1999; Peterson & McIlwraith, 2008; Setterbo et al., 2011; Setterbo et al., 2013), highlighting the importance of track maintenance between races on race day. There is a large gap in the literature on the type of training areas available to racing greyhounds. Racetrack surface and maintenance is an important factor in injury reduction, however, greyhounds only spend a small amount of their racing career on the racetrack. The type of activity, time spent training, and the training surfaces used for exercising racing greyhounds must be considered.

1.11.13 Number of dogs in a field

Interference during a race is common, occurring in up to 80% of greyhound races (Bloomberg & Dugger, 1998), often resulting in musculoskeletal injury. Early reports hypothesised that one way of reducing the interference and congestion during a race is to reduce the size of the field (Eager et al., 2017; Eager et al., 2018). To date, there is no peer reviewed literature to support this hypothesis. Other racing jurisdictions, including the United Kingdom and Ireland have six dog fields, however, there is limited recent data reporting normalised injury rates as well as environmental factors that differ between jurisdictions, for example position of the lure on the outside of the track and different starting box alignment.

In Thoroughbred racehorses, a greater number of starters has been associated with musculoskeletal injuries in some studies (Bailey et al., 1997; Parkin et al., 2004a), but no association between these variables has been found in other studies (Bailey et al., 1998; Cohen et al., 1999; Cohen et al., 2000b; Bolwell et al., 2017; Georgopoulos & Parkin, 2017). Physical interaction between horses has been associated with injuries (Cohen et al., 1997) and such interactions are more likely with a higher number of starters (Parkin et al., 2004a). Without the control of a jockey or driver, greyhounds are likely to jostle for position on the racetrack which may result in racing injuries.

1.11.14 Box position

Alignment of the starting boxes has been considered an important feature of safe track design in racing greyhounds (Hossain, 2020). Computational modelling has been used to analyse the effects of the position of the starting boxes in relation to the track. It is recognised that when the starting boxes are not well aligned, there is more likely to be path interference and abrupt changes in yaw rates and headings (Hossain et al., 2019; Hossain, 2020), both of which have been linked to increased incidence of injuries (Hossain, 2020). While the orientation of the starting boxes influences the greyhounds path trajectory, another important factor is the placement of the lure which will influence the greyhounds trajectory when exiting the starting boxes (Hayati, 2019; Hossain, 2020).

The placement of the starting boxes in relation to the bend is another factor considered to contribute to racing injuries. The run into the first bend is where the greatest amount of congestion will occur as greyhounds establish their racing position (Auer, 1999). Greyhounds are tightly packed as a group, as evidenced by mean distance from cluster centroid, for approximately the first seven seconds of the race, before dispersing (Hossain et al., 2019). A shorter approach to the bend will often mean greyhounds are more highly congested and interference is likely to occur. Sicard and colleagues (1999) suggested that the combination of a shorter straight and tighter second bend could have contributed to the higher injury rate seen at one of the tracks in their study. Moreover, greyhounds exiting boxes placed close to the bend, experience a changing high magnitude of centrifugal acceleration while accelerating to full speed (Hayati et al., 2019b; Hossain, 2020; Eager et al., 2021).

1.11.15 Starting position / number and individual greyhound racing style

In Australia and New Zealand, greyhounds are randomly allocated to one of eight starting boxes (Schneider et al., 2012). Bloomberg & Dugger (1998), Sicard et al. (1999) and Stevenson et al. (2009) all reported no significant effect of starting position and injury rate, however, Sicard and colleagues noted from their raw data that more injuries occurred in greyhounds starting from box four and fewest in greyhounds starting from the two outside boxes (seven and eight). Industry personnel and industry bodies allocating starting box position to a greyhound based on its preferred running style will help reduce interference and in turn, help to lower the incidence of injuries. Seeded box draws are utilised in other racing jurisdictions, for example the United Kingdom and Ireland. In 2022, GRNZ introduced preferential box draw races where greyhounds are assigned an early running trait (railer, straight, or wide runner). Raw data suggests a reduced incidence of injury for preferential box draw races (Greyhound Racing New Zealand, 2023b).

Research that investigated paw preference as a measure of cerebral lateralisation in 53 greyhounds in South Australia, found a relationship between paw preference and racing position on the track (Schneider et al., 2012). Greyhounds were seen to exhibit consistent behavioural biases while racing and attempted to race in their preferred position on the racetrack, regardless of the position of the lure (Schneider et al., 2012). It appears that the box number is not a risk factor for racing, but the box position in terms of a greyhounds preferred running trait is important in reducing racing collisions and resulting injuries. This finding is consistent with the GRNZ finding of a reduced incidence of injury for preferential box draw races.

1.12 SUMMARY

This review of the literature highlighted that training and racing practices are associated with the risk of musculoskeletal injuries and career longevity in racing greyhounds. Despite the omnipresent concerns, there is a lack of information on the management practices of these athletes. The influence of environment-, trainer- and animal- level risks for musculoskeletal injuries have been demonstrated in the equine model, where a number of risk factors have been identified. However, there is still a lack of understanding of many of these factors in racing greyhounds. It is evident that aspects of racing and training have the potential to impact the type and prevalence of injuries.

In order to fill this gap in knowledge, more information is required to understand the trends in racing frequency, what greyhounds are doing outside of racing, how these practices contribute to the dog's racing pattern (or vice-vera), and how these, along with environmental and animal factors, influence racing injuries. The racing industry must make informed decisions in order to impact greyhound welfare and address increasing societal concerns.

1.13 RESEARCH AIMS AND OBJECTIVES

Injuries of racing greyhounds pose a threat to the welfare of the animal and the economy of the industry. Any risk factors that can substantially reduce the incidence of injuries provide benefits to the racing industry. Frequency of racing has been suggested as a contributing factor to racing injuries, however, to date, frequency of racing has not been studied in racing greyhounds. The general training and racing patterns as well as the incidence of injuries occurring during racing needs to be described and quantified in order to determine if the frequency of racing is associated with incidence of injury or retirement from racing.

The primary aim of this thesis was to investigate the training and racing practices of racing greyhounds in New Zealand, and, to identify patterns and factors which influence the incidence of injury.

More specifically, this thesis aimed to address a deficit of scientific evidence on three important themes concerned with the health and welfare of New Zealand racing greyhounds. This may allow the development or modification of racing practices that could reduce the incidence of injuries and optimise greyhound welfare. Therefore, the specific aims addressed in this thesis are as follows:

The first theme identified was the lack of data providing baseline values for the frequency of racing in New Zealand greyhounds. *Chapter 2* aims to describe the patterns of racing and the career duration of racing greyhounds.

The second theme identified was the absence of available information on the training practices of racing greyhounds. *Chapter 3* documents baseline data collected with a cross-sectional survey on the training practices of young and racing greyhounds in New Zealand.

The final theme addressed was the inadequate information on risk factors for injuries that occur during racing that would influence the incidence of injuries sustained by racing greyhounds in New Zealand. *Chapter 4* aims to describe the frequency and type of injuries that occur in greyhounds. The information was then used to determine the common types of injuries for which multivariable logistic regression modelling could be used to determine environmental-level, race-level and dog-level risk factors associated with each injury type (*Chapter 5*).

Therefore, the specific objectives addressed in this thesis are:

1. Describe the pattern of racing and the career duration of racing greyhounds.
2. Describe the training and management of a cohort of racing greyhounds.
3. Describe the type and the incidence of injuries requiring a stand-down period or retirement from racing.
4. Quantify the effect of the frequency of racing in defined time periods, adjusting for dog-level, race-level, and trainer-level risk factors, on the risk of injury.

The outcomes of this research will benefit the greyhound racing industry by providing insights into racing patterns, training practices and common race-day injuries associated with racing greyhounds in New Zealand.

REFERENCES

Addis, P., & Lawson, S. (2010). The role of tendon stiffness in development of equine locomotion with age. *Equine Veterinary Journal*, *42*, 556-560.

Althubaiti, A. (2016). Information bias in health research: definition, pitfalls, and adjustment methods. *Journal of Multidisciplinary Healthcare*, *9*, 211.

Anthenill, L. A., Stover, S. M., Gardner, I. A., & Hill, A. E. (2007). Risk factors for proximal sesamoid bone fractures associated with exercise history and horseshoe characteristics in Thoroughbred racehorses. *American Journal of Veterinary Research*, *68*(7), 760-771.

Anthenill, L. A., Stover, S. M., Gardner, I. A., Hill, A. E., Lee, C. M., Anderson, M. L., Barr, B. C., Read, D. H., Johnson, B. J., & Woods, L. W. (2006). Association between findings on palmarodorsal radiographic images and detection of a fracture in the proximal sesamoid bones of forelimbs obtained from cadavers of racing Thoroughbreds. *American Journal of Veterinary Research*, *67*(5), 858-868.

Armstrong, R., Ogilvie, R., & Schwane, J. (1983). Eccentric exercise-induced injury to rat skeletal muscle. *Journal of Applied Physiology*, *54*(1), 80-93.

Armstrong, R., Saubert IV, C., Seeherman, H., & Taylor, C. (1982). Distribution of fiber types in locomotory muscles of dogs. *American Journal of Anatomy*, *163*(1), 87-98.

Arokoski, J., Kiviranta, I., Jurvelin, J., Tammi, M., & Helminen, H. J. (1993). Long-distance running causes site-dependent decrease of cartilage glycosaminoglycan content in the knee joints of beagle dogs. *Arthritis & Rheumatism: Official Journal of the American College of Rheumatology*, *36*(10), 1451-1459.

Auer, D., E. (1999). *Prevalence and type of injuries to racing greyhounds in South East Queensland.* World Greyhound Racing Federation Conference 2000, Sydney.

Bailey, C., Reid, S., Hodgson, D., Bourke, J., & Rose, R. (1998). Flat, hurdle and steeple racing: risk factors for musculoskeletal injury. *Equine Veterinary Journal*, *30*(6), 498-503.

Bailey, C., Reid, S., Hodgson, D., & Rose, R. (1999). Factors associated with time until first race and career duration for Thoroughbred racehorses. *American Journal of Veterinary Research*, *60*(10), 1196-1200.

Bailey, C., Reid, S., Hodgson, D., Suann, C., & Rose, R. (1997). Risk factors associated with musculoskeletal injuries in Australian Thoroughbred racehorses. *Preventive Veterinary Medicine*, *32*(1-2), 47-55.

Baker, J. S., McCormick, M. C., & Robergs, R. A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, *2010(1), 1-13.*.

Barneveld, A., & Van Weeren, P. (1999). Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine Veterinary Journal*, *31*(S31), 112-119.

Bass, S., Pearce, G., Bradney, M., Hendrich, E., Delmas, P. D., Harding, A., & Seeman, E. (1998). Exercise before puberty may confer residual benefits in bone density in adulthood: studies in active prepubertal and retired female gymnasts. *Journal of Bone and Mineral Research*, *13*(3), 500-507.

Bayly, W. M. (1985). Training programs. *Veterinary Clinics of North America: Equine Practice*, *1*(3), 597-610.

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190.

Bellenger, C., Johnson, K., Davis, P., & Ilkiw, J. (1981). Fixation of metacarpal and metatarsal fractures in greyhounds. *Australian Veterinary Journal*, *57*(5), 205-211.

Bennell, K., Malcolm, S., Wark, J., & Brukner, P. (1996). Models for the pathogenesis of stress fractures in athletes. *British Journal of Sports Medicine*, *30*(3), 200-204.

Bentolila, V., Boyce, T., Fyhrie, D., Drumb, R., Skerry, T., & Schaffler, M. B. (1998). Intracortical remodeling in adult rat long bones after fatigue loading. *Bone*, *23*(3), 275-281.

Bergh, M. S., Piras, A., Samii, V. F., Weisbrode, S. E., & Johnson, K. A. (2012). Fractures in regions of adaptive modeling and remodeling of central tarsal bones in racing greyhounds. *American Journal of Veterinary Research*, *73*(3), 375-380.

Bhatt, V. S., Zaldívar-López, S., Harris, D. R., Couto, C. G., Wang, P. G., & Palmer, A. F. (2011). Structure of greyhound hemoglobin: origin of high oxygen affinity. *Acta Crystallographica Section D: Biological Crystallography*, *67*(5), 395-402.

Birch, H. L. (2007). Tendon matrix composition and turnover in relation to functional requirements. *International Journal of Experimental Pathology, 88*(4), 241-248.

Birch, H. L., McLaughlin, L., Smith, R., & Goodship, A. (1999). Treadmill exercise-induced tendon hypertrophy: assessment of tendons with different mechanical functions. *Equine Veterinary Journal*, *31*(S30), 222-226.

Birkinshaw, V. (2006). Greyhound racing: Greyhound racing in New Zealand. *New Zealand Geographic*, 080. Retrieved 24 April 2019 from https://www.nzgeo.com/stories/greyhound-racing/.

Bloomberg, M., & Dugger, W. (1998). Greyhound racing injuries: racetrack injury survey. In: M. S. Bloomberg, J. F. Dee, and R.A. Taylor (Eds.), *Canine sports medicine and surgery* (pp. 412-415). W.B. Saunders Company, Philadelphia, United States of America.

Blythe, L. L., Gannon, J. R., Craig, A. M., & Fegan, D. P. (2007). *Care of the racing & retired greyhound* (1st ed.). Hall Commercial Printing, Kansas, United States of America.

Boden, L., Anderson, G., Charles, J., Morgan, K., Morton, J., Parkin, T., Clarke, A., & Slocombe, R. (2007). Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989–2004). *Equine Veterinary Journal*, *39*(5), 430-437.

Boden, L., Anderson, G., Charles, J., Morgan, K., Morton, J., Parkin, T., Slocombe, R., & Clarke, A. (2006). Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989–2004. *Equine Veterinary Journal*, *38*(4), 312-318.

Boivin, G., Farlay, D., Bala, Y., Doublier, A., Meunier, P. J., & Delmas, P. D. (2009). Influence of remodeling on the mineralization of bone tissue. *Osteoporosis International*, *20*, 1023-1026.

Bolwell, C., Rogers, C., French, N., & Firth, E. (2013). The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Preventive Veterinary Medicine*, *108*(2-3), 188-198.

Bolwell, C., Rogers, C., French, N., & Firth, E. (2012a). Risk factors for interruptions to training occurring before the first trial start of 2-year-old Thoroughbred racehorses. *New Zealand Veterinary Journal*, *60*(4), 241-246.

Bolwell, C., Rogers, C., Gee, E., & McIlwraith, W. (2017). Epidemiology of musculoskeletal injury during racing on New Zealand racetracks 2005–2011. *Animals*, *7*(8), 62.

Bolwell, C., Russell, L., & Rogers, C. (2010). A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comparative Exercise Physiology*, *7*(1), 37-42.

Bolwell, C. F. (2011). *Epidemiological studies of early exercise and measures of training and racing performance in thoroughbred racehorses* [Doctoral dissertation, Massey University]. Massey Research Online. http://hdl.handle.net/10179/2989.

Bolwell, C. F., Rogers, C. W., French, N. P., & Firth, E. C. (2012b). Associations between yearling exercise and interruptions during race training in Thoroughbred racehorses. *American Journal of Veterinary Research*, *73*(10), 1610-1616.

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2014a). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science*, *56*(1), 77-81.

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2014b). Descriptive statistics and the pattern of horse racing in New Zealand. 2. Harness racing. *Animal Production Science*, *56*(1), 82-86.

Bolwell, C. F., Rogers, C. W., Rosanowski, S. M., Weston, J. F., Gee, E. K., & Gordon, S. J. (2015). Cross-sectional survey of the management and training practices of endurance horses in New Zealand: A pilot study. *Journal of Equine Veterinary Science*, *35*(10), 801-806.

Boston, R. C., & Nunamaker, D. M. (2000). Gait and speed as exercise components of risk factors associated with onset of fatigue injury of the third metacarpal bone in 2-year-old Thoroughbred racehorses. *American Journal of Veterinary Research*, *61*(6), 602-608.

Boudrieau, R., Dee, J., & Dee, L. (1984a). Central tarsal bone fractures in the racing Greyhound: a review of 114 cases. *Journal of the American Veterinary Medical Association*, *184*(12), 1486-1491.

Boudrieau, R., Dee, J., & Dee, L. (1984b). Treatment of central tarsal bone fractures in the racing Greyhound. *Journal of the American Veterinary Medical Association*, *184*(12), 1492-1500.

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. (2017). Monitoring athlete training loads: consensus statement. *International Journal of Sports Physiology and Performance*, *12*(s2), S2-161-S2-170.

Boyce, T. M., Fyhrie, D. P., Glotkowski, M. C., Radin, E. L., & Schaffler, M. B. (1998). Damage type and strain mode associations in human compact bone bending fatigue. *Journal of Orthopaedic Research*, *16*(3), 322-329.

Boyde, A. (2003). The real response of bone to exercise. *Journal of Anatomy*, *203*(2), 173-189.

Boyde, A., & Firth, E. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 8. Quantitative back-scattered electron scanning electron microscopy and confocal fluorescence microscopy of the epiphysis of the third metacarpal bone. *New Zealand Veterinary Journal*, *53*(2), 123-132.

Boyde, A., Riggs, C., & Firth, E. (2001). Densification by infilling marrow space in response to exercise in thoroughbred horse distal cannon bone. Bone, 28(5), S110.

Brama, P., Tekoppele, J., Bank, R., Barneveld, A., Firth, E., & Weeren, P. V. (2000a). The influence of strenuous exercise on collagen characteristics of articular cartilage in Thoroughbreds age 2 years. *Equine Veterinary Journal*, *32*(6), 551-554.

Brama, P., TeKoppele, J., Bank, R., Barneveld, A., & Van Weeren, P. v. (2002). Development of biochemical heterogeneity of articular cartilage: influences of age and exercise. *Equine Veterinary Journal*, *34*(3), 265-269.

Brama, P., Tekoppele, J., Bank, R., Karssenberg, D., Barneveld, A., & Van Weeren, P. (2000b). Topographical mapping of biochemical properties of articular cartilage in the equine fetlock joint. *Equine Veterinary Journal*, *32*(1), 19-26.

Brandt, K. D., Dieppe, P., & Radin, E. L. (2009). Commentary: is it useful to subset" primary" osteoarthritis? A critique based on evidence regarding the etiopathogenesis of osteoarthritis. *Seminars in Arthritis and Rheumatism*, 39(2), 81-95.

Branigan, C. A. (2004). *The reign of the greyhound: a popular history of the oldest family of dogs*. Howell Book House, New Jersey, United States of America.

Branson, N. J., Cobb, M. L., & McGreevy, P. D. (2009). Australian Working Dog Survey Report. *Australian Government Department of Agriculture Fisheries and Forestries,* Canberra, Australia.

Brommer, H., Brama, P., Laasanen, M., Helminen, H., Van Weeren, P., & Jurvelin, J. (2005). Functional adaptation of articular cartilage from birth to maturity under the influence of loading: a biomechanical analysis. *Equine Veterinary Journal, 37*(2), 148-154.

Bullough, P., Goodfellow, J., & O'Connor, J. (1973). The relationship between degenerative changes and load-bearing in the human hip. *The Journal of Bone and Joint Surgery,* 55(4), 746-758.

Burr, D., Schaffler, M., Yang, K., Lukoschek, M., Sivaneri, N., Blaha, J., & Radin, E. (1989). Skeletal change in response to altered strain environments: Is woven bone a response to elevated strain? *Bone, 10*(3), 223-233.

Burr, D. B., Forwood, M. R., Fyhrie, D. P., Martin, R. B., Schaffler, M. B., & Turner, C. H. (1997). Bone microdamage and skeletal fragility in osteoporotic and stress fractures. *Journal of Bone and Mineral Research, 12*(1), 6-15.

Burr, D. B., Martin, R. B., Schaffler, M. B., & Radin, E. L. (1985). Bone remodeling in response to in vivo fatigue microdamage. *Journal of Biomechanics*, *18*(3), 189-200.

Carrier, T. K., Estberg, L., Stover, S. M., Gardner, I., Johnson, B. J., Read, D. H., & Ardans, A. (1998). Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in thoroughbred racehorses: 54 cases (1991-1994). *Journal of the American Veterinary Medical Association*, *212*(10), 1582-1587.

Carter, D. R., Caler, W. E., Spengler, D. M., & Frankel, V. H. (1981). Uniaxial fatigue of human cortical bone. The influence of tissue physical characteristics. *Journal of Biomechanics, 14*(7), 461-470.

Carter, D. R., & Hayes, W. C. (1977). Compact bone fatigue damage: a microscopic examination. *Clinical Orthopaedics and Related Research (1976-2007), 127*, 265-274.

Cherdchutham, W., Becker, C., Smith, R., Barneveld, A., & Van Weeren, P. (1999). Age-related changes and effect of exercise on the molecular composition of immature equine superficial digital flexor tendons. *Equine Veterinary Journal*, *31*(S31), 86-94.

Cherdchutham, W., Meershoek, L. S., van Weeren, P. R., & Barneveld, A. (2001). Effects of exercise on biomechanical properties of the superficial digital flexor tendon in foals. *American Journal of Veterinary Research*, *62*(12), 1859-1864.

Cheung, K. L., Peter, M., Smit, C., de Vries, H., & Pieterse, M. E. (2017). The impact of non-response bias due to sampling in public health studies: a comparison of voluntary versus mandatory recruitment in a Dutch national survey on adolescent health. *BMC Public Health*, *17*(1), 1-10.

Clarke, B. (2008). Normal Bone Anatomy and Physiology. *Clinical Journal of the American Society of Nephrology*, *3*(Suppl 3), S131-S139.

Cobb, M., Branson, N., McGreevy, P., Lill, A., & Bennett, P. (2015). The advent of canine performance science: offering a sustainable future for working dogs. *Behavioural Processes*, *110*, 96-104.

Cobb, M., Lill, A., & Bennett, P. (2020). Not all dogs are equal: Perception of canine welfare varies with context. *Animal Welfare*, *29*(1), 27-35.

Cogger, N. (2006). *Epidemiology of musculoskeletal injuries in two-and three-year-old Australian Thoroughbred racehorses* [Doctoral dissertation, The University of Sydney. Sydney, Australia]. Sydney eScholarship Repository. http://hdl.handle.net/2123/1611.

Cogger, N., Evans, D., Hodgson, D., Reid, S., & Perkins, N. (2008a). Incidence rate of musculoskeletal injuries and determinants of time to recovery in young Australian Thoroughbred racehorses. *Australian Veterinary Journal*, *86*(12), 473-480.

Cogger, N., Perkins, N., Hodgson, D., Reid, S., & Evans, D. (2008b). Profiling training preparation in young Australian Thoroughbred racehorses. *Australian Veterinary Journal*, *86*(11), 419-424.

Cogger, N., Perkins, N., Hodgson, D., Reid, S., & Evans, D. (2006). Risk factors for musculoskeletal injuries in 2-year-old Thoroughbred racehorses. *Preventive Veterinary Medicine*, *74*(1), 36-43.

Cohen, N., Berry, S., Peloso, J., Mundy, G., & Howard, I. (2000a). Thoroughbred racehorses that sustain injury accumulate less high speed exercise compared to horses without injury in Kentucky. *Proceedings of the 46th American Association of Equine Practitioners Meeting*, pp 51-53.

Cohen, N., Mundy, G., Peloso, J., Carey, V., & Amend, N. (1999). Results of physical inspection before races and race-related characteristics and their association with musculoskeletal injuries in thoroughbreds during races. *Journal of the American Veterinary Medical Association*, *215*(5), 654-661.

Cohen, N., Peloso, J., Mundy, G., Fisher, M., Holland, R., Little, T., Misheff, M., Watkins, J., Honnas, C., & Moyer, W. (1997). Racing-related factors and results of prerace physical inspection and their association with musculoskeletal injuries incurred in thoroughbreds during races. *Journal of the American Veterinary Medical Association*, *211*(4), 454-463.

Cohen, N. D., Berry, S. M., Peloso, J. G., Mundy, G. D., & Howard, I. C. (2000b). Association of high-speed exercise with racing injury in Thoroughbreds. *Journal of the American Veterinary Medical Association*, *216*(8), 1273-1278.

Colgan, B., Neil, C., & Foy, L. (2013). *New Zealand Greyhound Racing Association, Independant Welfare Review*. WHK.

Cook, A. (1998). Literature survey of racing greyhound injuries, performance and track conditions. *Journal of Turfgrass Science*, *74*, 108-113.

Cornelissen, B., Van Weeren, P., Ederveen, A., & Barneveld, A. (1999). Influence of exercise on bone mineral density of immature cortical and trabecular bone of the equine metacarpus and proximal sesamoid bone. *Equine Veterinary Journal*, *31*(S31), 79-85.

Crawford, K. L., Ahern, B. J., Perkins, N. R., Phillips, C. J., & Finnane, A. (2020a). The Effect of Combined Training and Racing High-Speed Exercise History on Musculoskeletal Injuries in Thoroughbred Racehorses: A Systematic Review and Meta-Analysis of the Current Literature. *Animals*, *10*(11), 2091.

Crawford, K. L., Finnane, A., Greer, R. M., Barnes, T. S., Phillips, C. J., Woldeyohannes, S. M., Bishop, E. L., Perkins, N. R., & Ahern, B. J. (2021a). Survival Analysis of Training Methodologies and Other Risk Factors for Musculoskeletal Injury in 2-Year-Old Thoroughbred Racehorses in Queensland, Australia. *Frontiers in Veterinary Science*, *8*:698298.

Crawford, K. L., Finnane, A., Greer, R. M., Phillips, C. J., Bishop, E. L., Woldeyohannes, S. M., Perkins, N. R., & Ahern, B. J. (2021b). A Prospective Study of Training Methods for Two-Year-Old Thoroughbred Racehorses in Queensland, Australia, and Analysis of the Differences in Training Methods between Trainers of Varying Stable Sizes. *Animals*, *11*(4), 928.

Crawford, K. L., Finnane, A., Greer, R. M., Phillips, C. J., Woldeyohannes, S. M., Perkins, N. R., & Ahern, B. J. (2020b). Appraising the Welfare of Thoroughbred Racehorses in Training in Queensland, Australia: The Incidence and Type of Musculoskeletal Injuries Vary between Two-Year-Old and Older Thoroughbred Racehorses. *Animals*, *10*(11), 2046.

Crevier-Denoix, N., Robin, D., Pourcelot, P., Falala, S., Holden, L., Estoup, P., Desquilbet, L., Denoix, J.-M., & Chateau, H. (2010). Ground reaction force and kinematic analysis of limb loading on two different beach sand tracks in harness trotters. *Equine Veterinary Journal*, *42*, 544-551.

Cruz, A. M., Poljak, Z., Filejski, C., Lowerison, M. L., Goldie, K., Martin, S. W., & Hurtig, M. B. (2007). Epidemiologic characteristics of catastrophic musculoskeletal injuries in Thoroughbred racehorses. *American Journal of Veterinary Research*, *68*(12), 1370-1375.

Cunningham, E., Dooley, J. J., Splan, R., & Bradley, D. (2001). Microsatellite diversity, pedigree relatedness and the contributions of founder lineages to thoroughbred horses. *Animal Genetics*, *32*(6), 360-364.

Danova, N., Colopy, S., Radtke, C., Kalscheur, V., Markel, M., Vanderby Jr, R., McCabe, R., Escarcega, A., & Muir, P. (2003). Degradation of bone structural properties by accumulation and coalescence of microcracks. *Bone*, *33*(2), 197-205.

Davis, P. (1971). Shin soreness in the racing greyhound. *The Veterinary Record*, *89*(23), 610-611.

Davis, P. (1973). Toe and muscle injuries of the racing greyhound. *New Zealand Veterinary Journal*, *21*(7), 133-146.

Davis, P. E. (1967). Track injuries in racing greyhounds. *Australian Veterinary Journal*, *43*(5), 180-191.

Denny, M. W. (2008). Limits to running speed in dogs, horses and humans. *Journal of Experimental Biology*, *211*(24), 3836-3849.

Dobson, G. P., Parkhouse, W. S., Weber, J.-M., Stuttard, E., Harman, J., Snow, D. H., & Hochachka, P. W. (1988). Metabolic changes in skeletal muscle and blood of greyhounds during 800-m track sprint. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *255*(3), R513-R519.

Dockerty, R. J. (2017). *A Multifactorial Genetic Approach to Improving Welfare in the Racing Greyhound* [Doctoral dissertation, University of Liverpool]. The University of Liverpool Repository. https://livrepository.liverpool.ac.uk/id/eprint/3012340.

Dohoo, I. R., Martin, W., & Stryhn, H. E. (2009). *Veterinary Epidemiologic Research* (2nd ed.). VER Inc. Charlottetown, Canada.

Donald, D. E., Milburn, S. E., & Shepherd, J. T. (1964). Effect of cardiac denervation on the maximal capacity for exercise in the racing greyhound. *Journal of Applied Physiology*, *19*(5), 849-852.

Druett, J. (1983). *Exotic Intruders: The introduction of plants and animals into New Zealand*. Heinemann, London, United Kingdom.

Duarte, J., Appell, H.-J., Carvalho, F., Bastos, M., & Soares, J. (1993). Endothelium-derived oxidative stress may contribute to exercise-induced muscle damage. *International Journal of Sports Medicine*, *14*(08), 440-443.

Dupont, G., Moalla, W., Guinhouya, C., Ahmaidi, S., & Berthoin, S. (2004). Passive versus active recovery during high-intensity intermittent exercises. *Medicine & Science in Sports & Exercise*, *36*(2), 302-308.

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: a systematic review with meta-analysis. *Frontiers in Physiology, 9*, 403.

Dykgraaf, S., Firth, E. C., Rogers, C. W., & Kawcak, C. E. (2008). Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *The Veterinary Journal*, *178*(1), 53-61.

Eager, D., Hayati, H., & Hossain, M. (2017). *Identifying optimal greyhound track design for greyhound safety and welfare. Phase I Report January 2016 to 31 December 2016*. University of Technology Sydney.

Eager, D., Hayati, H., Mahdavi, F., Hossain, M., Stephenson, R., & Thomas, N. (2018). *Identifying optimal greyhound track design for greyhound safety and welfare-Phase II-Progress Report-1 January 2016 to 31 December 2017*. University of Technology Sydney.

Eager, D., Hossain, I., Ishac, K., & Robins, S. (2021). Analysis of Racing Greyhound Path Following Dynamics Using a Tracking System. *Animals, 11*(9), 2687.

Eager, D., Pendrill, A.-M., & Reistad, N. (2016). Beyond velocity and acceleration: jerk, snap and higher derivatives. *European Journal of Physics, 37*(6), 065008.

Eaton, M., Hodgson, D., Evans, D., & Rose, R. (1999). Effects of low-and moderate-intensity training on metabolic responses to exercise in Thoroughbreds. *Equine Veterinary Journal*, *31*(S30), 521-527.

Eckard, T. G., Padua, D. A., Hearn, D. W., Pexa, B. S., & Frank, B. S. (2018). The relationship between training load and injury in athletes: a systematic review. *Sports Medicine*, *48*(8), 1929-1961.

Ely, E., Price, J., Smith, R., Wood, J., & Verheyen, K. (2010). The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine Veterinary Journal*, *42*, 624-629.

Ely, E. R., Avella, C. S., Price, J. S., Smith, R. K., Wood, J. L., & Verheyen, K. L. (2009). Descriptive epidemiology of fracture, tendon and suspensory ligament injuries in National Hunt racehorses in training. *Equine Veterinary Journal*, *41*(4), 372-378.

Emmerson, T. D., Lawes, T. J., Goodship, A. E., Rueux-Mason, C., & Muir, P. (2000). Dual-energy X-ray absorptiometry measurement of bone-mineral density in the distal aspect of the limbs in racing Greyhounds. *American Journal of Veterinary Research*, *61*(10), 1214-1219.

Epp, T., Erickson, H., Woodworth, J., & Poole, D. (2007). Effects of oral L-carnitine supplementation in racing Greyhounds. *Comparative Exercise Physiology*, *4*(3-4), 141.

Essen, B., Jansson, E., Henriksson, J., Taylor, A., & Saltin, B. (1975). Metabolic characteristics of fibre types in human skeletal muscle. *Acta Physiologica Scandinavica*, *95*(2), 153-165.

Estberg, L., Gardner, I. A., Stover, S. M., & Johnson, B. J. (1998a). A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California Thoroughbred racehorses. *Preventive Veterinary Medicine*, *33*(1-4), 159-170.

Estberg, L., Gardner, I. A., Stover, S. M., Johnson, B. J., Case, J. T., & Ardans, A. (1995). Cumulative racing-speed exercise distance cluster as a risk factor for fatal musculoskeletal injury in Thoroughbred racehorses in California. *Preventive Veterinary Medicine*, *24*(4), 253-263.

Estberg, L., Stover, S. M., Gardner, I., Drake, C. M., Johnson, B., & Ardans, A. (1996a). High-speed exercise history and catastrophic racing fracture in thoroughbreds. *American Journal of Veterinary Research*, *57*(11), 1549-1555.

Estberg, L., Stover, S. M., Gardner, I., Johnson, B., Case, J., Ardans, A., Read, D., Anderson, M. L., Barr, B., & Daft, B. (1996b). Fatal musculoskeletal injuries incurred during racing and training in thoroughbreds. *Journal of the American Veterinary Medical Association*, *208*(1), 92-96.

Estberg, L., Stover, S. M., Gardner, I. A., Johnson, B. J., Jack, R. A., Case, J. T., Ardans, A., Read, D. H., Anderson, M. L., & Barr, B. C. (1998b). Relationship between race start characteristics and risk of catastrophic injury in thoroughbreds: 78 cases (1992). *Journal of the American Veterinary Medical Association*, *212*(4), 544-549.

Etter, J.-F., & Perneger, T. V. (1997). Analysis of non-response bias in a mailed health survey. *Journal of Clinical Epidemiology, 50*(10), 1123-1128.

Euser, A. M., Zoccali, C., Jager, K. J., & Dekker, F. W. (2009). Cohort studies: prospective versus retrospective. *Nephron Clinical Practice*, *113*(3), c214-c217.

Evans, D., & Walsh, J. (1997). Effect of increasing the banking of a racetrack on the occurrence of injury and lameness in standardbred horses. *Australian Veterinary Journal*, *75*(10), 751-752.

Evans, G., Behiri, J., Vaughan, L., & Bonfield, W. (1992). The response of equine cortical bone to loading at strain rates experienced in vivo by the galloping horse. *Equine Veterinary Journal*, *24*(2), 125-128.

Firth, E., Doube, M., & Boyde, A. (2009). Changes in mineralised tissue at the site of origin of condylar fracture are present before athletic training in Thoroughbred horses. *New Zealand Veterinary Journal*, *57*(5), 278-283.

Firth, E., & Rogers, C. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 7. Bone and articular cartilage response in the carpus. *New Zealand Veterinary Journal*, *53*(2), 113-122.

Firth, E., Rogers, C., & Anderson, B. (2004a). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 4. Morphometric, microscopic and biomechanical properties of the digital tendons of the forelimb. *New Zealand Veterinary Journal*, *52*(5), 285-292.

Firth, E., Rogers, C., Doube, M., & Jopson, N. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 6. Bone parameters in the third metacarpal and third metatarsal bones. *New Zealand Veterinary Journal*, *53*(2), 101-112.

Firth, E., Rogers, C., Perkins, N., Anderson, B., & Grace, N. (2004b). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 1. Study design, and clinical, nutritional, radiological and histological observations. *New Zealand Veterinary Journal*, *52*(5), 261-271.

Firth, E. C., Rogers, C. W., van Weeren, P. R., Barneveld, A., McIlwraith, C. W., Kawcak, C. E., Goodship, A. E., & Smith, R. K. (2012). The effect of previous conditioning exercise on diaphyseal and metaphyseal bone to imposition and withdrawal of training in young Thoroughbred horses. *The Veterinary Journal*, *192*(1), 34-40.

Firth, E. C., Rogers, C. W., van Weeren, P. R., Barneveld, A., McIlwraith, C. W., Kawcak, C. E., Goodship, A. E., & Smith, R. K. (2011). Mild exercise early in life produces changes in bone size and strength but not density in proximal phalangeal, third metacarpal and third carpal bones of foals. *The Veterinary Journal*, *190*(3), 383-389.

Flash, M., Crabb, H., Hitchens, P., Firestone, S., Stevenson, M., & Gilkerson, J. (2022a). Factors associated with racing performance and career duration for Victorian-born Thoroughbreds. *Australian Veterinary Journal*, *100*(1-2), 48-55.

Flash, M., Crabb, H., Hitchens, P., Firestone, S., Stevenson, M., & Gilkerson, J. (2022b). Participation of Victorian thoroughbreds in the racing industry: a whole-of-population benchmark. *Australian Veterinary Journal*, *100*(1-2), 40-47.

Flash, M. L., Renwick, M., Gilkerson, J. R., & Stevenson, M. A. (2020). Descriptive analysis of Thoroughbred horses born in Victoria, Australia, in 2010; barriers to entering training and outcomes on exiting training and racing. *PloS One*, *15*(10), e0241273.

Fowler Jr, F. J. (2014). *Survey research methods*. Sage Publications, United States of America.

Fredricson, I., Dalin, G., Drevemo, S., Hjerten, G., & Alm, L. (1975). A biotechnical approach to the geometric design of racetracks. *Equine Veterinary Journal*, *7*(2), 91-96.

Fonseca, S. T., Souza, T. R., Verhagen, E., Van Emmerik, R., Bittencourt, N. F., Mendonça, L. D., Andrade, A. G. P., Resende, R. A., & Ocarino, J. M. (2020). Sports injury forecasting and complexity: a synergetic approach. *Sports Medicine*, *50*, 1757-1770.

Frost, H. M. (1987). Bone "mass" and the "mechanostat": a proposal. *The Anatomical Record*, *219*(1), 1-9.

Fulcher, G. R., Hukins, D. W., & Shepherd, D. E. (2009). Viscoelastic properties of bovine articular cartilage attached to subchondral bone at high frequencies. *BMC Musculoskeletal Disorders*, *10*(1), 1-7.

Gabbett, T. J. (2003). Incidence of injury in semi-professional rugby league players. *British Journal of Sports Medicine*, *37*(1), 36-44.

Gabbett, T. J. (2004). Influence of training and match intensity on injuries in rugby league. *Journal of Sports Sciences*, *22*(5), 409-417.

Gabbett, T. J., & Domrow, N. (2007). Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *Journal of Sports Sciences*, *25*(13), 1507-1519.

Gabbett, T. J., Hulin, B. T., Blanch, P., & Whiteley, R. (2016). High training workloads alone do not cause sports injuries: how you get there is the real issue. *British Journal of Sports Medicine*, *50*(8), 444-445.

Gannon, A., Nagel, T., Bell, A., Avery, N., & Kelly, D. (2015). Postnatal changes to the mechanical properties of articular cartilage are driven by the evolution of its collagen network. *European Cells and Materials*, *29*, 105-123-.

Gannon, J. (1972). Stress fractures in the greyhound. *Australian Veterinary Journal*, *48*(5), 244-250.

Georgopoulos, S. P., & Parkin, T. D. (2016). Risk factors associated with fatal injuries in Thoroughbred racehorses competing in flat racing in the United States and Canada. *Journal of the American Veterinary Medical Association*, *249*(8), 931-939.

Georgopoulos, S. P., & Parkin, T. D. (2017). Risk factors for equine fractures in Thoroughbred flat racing in North America. *Preventive Veterinary Medicine*, *139*, 99-104.

Gibbs, P., Potter, G., Nielsen, B., Householder, D., & Moyer, W. (1995). Scientific principles for conditioning race and performance horses. *The Professional Animal Scientist*, *11*(4), 195-203.

Gillette, R. L. (2007). Optimizing performance and prevent injuries of the canine sprint athlete. In *Proceedings of the North American Veterinary Conference* (pp 1324 – 1327). Orlando, United States of America.

Gillis, C., Pool, R., Meagher, D., Stover, S., Reiser, K., & Willits, N. (1997). Effect of maturation and aging on the histomorphometric and biochemical characteristics of equine superficial digital flexor tendon. *American Journal of Veterinary Research*, *58*(4), 425-430.

Gladden, L. (2004). Lactate metabolism: a new paradigm for the third millennium. *The Journal of Physiology*, *558*(1), 5-30.

Granatosky, M. C. (2019). Greyhound Racing. In J. Vonk & T. Shackelford (Eds.), *Encyclopedia of animal cognition and behavior* (pp. 1-3). Springer International Publishing, Switzerland.

Greyhound Board of Great Britain. (2022). *Rule 147 – Greyhound not to run more than once in a four day period*. Greyhound Board of Great Britain. Retrieved 9 June 2023 from https://rules.gbgb.org.uk/section-7-trials-meetings-and-race-meetings/rule-147-greyhound-not-to-run-more-than-twice-in-day/#:~:text=A%20Greyhound%20shall%20not%20run,do%20not%20count%20as%20runs.

Greyhound Racing New Zealand. (2019). *Clubs & Tracks*. Greyhound Racing New Zealand Retrieved 30 May 2019 from https://www.grnz.co.nz/catch-the-action/clubs-and-venues.aspx

Greyhound Racing New Zealand. (n.d.). *Fields Index*. Greyhound Racing New Zealand. Retrieved 30 May 2019 from https://www.grnz.co.nz/catch-the-action/fields.aspx

Greyhound Racing New Zealand. (2023a). *Greyhound Welfare Standards: Minimum Standards for the Care and Welfare of Greyhounds*. Greyhound Racing New Zealand. Retrieved 29 August 2023 from https://www.grnz.co.nz/Files/Rules%20and%20Policies/Greyhound%20Welfare%20Standards%202023%20WEB.pdf

Greyhound Racing New Zealand. (2023b). *GRNZ Animal Welfare Progress Report*. Greyhound Racing New Zealand. Retrieved 12 September 2023 from https://www.grnz.co.nz/Files/Quarterly%20Reports/Final%20GRNZ%20Quarterly%20Report%2031%20July%202023.pdf

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association. https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf.

Greyhound Racing Victoria. (2019). *Attendant and Trainer Education Pack: Unit Two - Owner Trainer. Booklet 9 - Education and Training*. Greyhound Racing Victoria. Retrieved 22 April 2020 from https://greyhoundcare.grv.org.au/wp-content/uploads/2019/07/Greyhound-Racing-Victoria-Animal-Welfare-Booklet-9-Education-and-Training.pdf.

Grimes, D. A., & Schulz, K. F. (2002). Bias and causal associations in observational research. *The Lancet*, *359*(9302), 248-252.

Gu, J., Orr, N., Park, S. D., Katz, L. M., Sulimova, G., MacHugh, D. E., & Hill, E. W. (2009). A genome scan for positive selection in thoroughbred horses. *PloS One*, *4*(6), e5767.

Guilliard, M. (2005). Centrodistal joint lameness in dogs. *Journal of Small Animal Practice*, *46*(4), 199-202.

Guilliard, M. (2013). Conservative management of fractures of the third metatarsal bone in the racing greyhound. *Journal of Small Animal Practice*, *54*(10), 507-511.

Guilliard, M. (1997). Dorsal radiocarpal ligament sprain causing intermittent carpal lameness in high activity dogs. *Journal of Small Animal Practice, 38*(10), 463-465.

Guilliard, M. (2003). Dorsal tarsal instability in three racing greyhounds. *Journal of Small Animal Practice*, *44*(9), 415-417.

Guilliard, M. (1998). Enthesiopathy of the short radial collateral ligaments in racing greyhounds. *Journal of Small Animal Practice*, *39*(5), 227-230.

Guilliard, M., & Mayo, A. (2000). Sprain of the short radial collateral ligament in a racing greyhound. *Journal of Small Animal Practice*, *41*(4), 169-171.

Gunn, H. (1989). Heart weight and running ability. *Journal of Anatomy*, *167*, 225.

Guy, P., & Snow, D. (1981). Skeletal muscle fibre composition in the dog and its relationship to athletic ability. *Research in Veterinary Science, 31*(2), 244-248.

Hampton, J. O., Jones, B., & McGreevy, P. D. (2020). Social license and animal welfare: Developments from the past decade in Australia. *Animals*, *10*(12), 2237.

Hansen, R. (2017). *Report to New Zealand Racing Board on welfare issues affecting greyhound racing in New Zealand*. New Zealand Racing Board.

Harris, R., Marlin, D., & Snow, D. (1987). Metabolic response to maximal exercise of 800 and 2,000 m in the thoroughbred horse. *Journal of Applied Physiology*, *63*(1), 12-19.

Harrison, S. M., Whitton, R. C., Kawcak, C. E., Stover, S. M., & Pandy, M. G. (2010). Relationship between muscle forces, joint loading and utilization of elastic strain energy in equine locomotion. *Journal of Experimental Biology*, *213*(23), 3998-4009.

Hayati, H. (2019). *Locomotion dynamics of agile canines* [Doctoral dissertation, University of Technology Sydney]. OPUS: Open Publications of UTS Scholars. http://hdl.handle.net/10453/140535.

Hayati, H., Eager, D., Jusufi, A., & Brown, T. (2017a). A study of rapid tetrapod running and turning dynamics utilizing inertial measurement units in greyhound sprinting. In *Proceedings of the ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Volume 3: 19th International Conference on Advanced Vehicle Technologies; 14th International Conference on Design Education; 10th Frontiers in Biomedical Devices (pp 1 – 5)*. Cleveland, Ohio, United States of America.

Hayati, H., Eager, D., Peham, C., & Qi, Y. (2020). Dynamic Behaviour of High Performance of Sand Surfaces Used in the Sports Industry. *Vibration*, *3*(4), 410-424.

Hayati, H., Eager, D., Stephenson, R., Brown, T., & Arnott, E. (2017b). The impact of track related parameters on catastrophic injury rate of racing greyhounds. In *9th Australasian Congress on Applied Mechanics* (pp 311-317). Sydney Engineers Australia.Hayati, H., Eager, D., & Walker, P. (2019a). The effects of surface compliance on greyhound galloping dynamics. *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, *233*(4), 1033-1043.

Hayati, H., Mahdavi, F., & Eager, D. (2019b). Analysis of agile canine gait characteristics using accelerometry. *Sensors*, *19*(20), 4379.

Heleski, C., Stowe, C. J., Fiedler, J., Peterson, M. L., Brady, C., Wickens, C., & MacLeod, J. N. (2020). Thoroughbred Racehorse Welfare through the Lens of 'Social License to Operate—With an Emphasis on a US Perspective. *Sustainability*, *12*(5), 1706.

Henderson, L. E. (2022). Gone to the Dogs? A case study evaluation of contemporary greyhound racing regulation in New South Wales. *Animal Studies Journal*, *11*(1), 256-283.

Hercock, C. A. (2010). *Specialisation for fast locomotion: performance, cost and risk* [Doctoral dissertation, University of Liverpool]. University of Liverpool Repository. https://livrepository.liverpool.ac.uk/id/eprint/3453.

Herman, B. C., Cardoso, L., Majeska, R. J., Jepsen, K. J., & Schaffler, M. B. (2010). Activation of bone remodeling after fatigue: differential response to linear microcracks and diffuse damage. *Bone*, *47*(4), 766-772.

Hernandez, C. J., Gupta, A., & Keaveny, T. M. (2006). A biomechanical analysis of the effects of resorption cavities on cancellous bone strength. *Journal of Bone and Mineral Research*, *21*(8), 1248-1255.

Hernandez, J., Hawkins, D. L., & Scollay, M. C. (2001). Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *Journal of the American Veterinary Medical Association*, *218*(1), 83-86.

Hernandez, J. A., Scollay, M. C., Hawkins, D. L., Corda, J. A., & Krueger, T. M. (2005). Evaluation of horseshoe characteristics and high-speed exercise history as possible risk factors for catastrophic musculoskeletal injury in Thoroughbred racehorses. *American Journal of Veterinary Research*, *66*(8), 1314-1320.

Hickman, J. (1975). Greyhound injuries. *Journal of Small Animal Practice*, *16*(1-12), 455-460.

Hill, A. E., Gardner, I. A., Carpenter, T. E., & Stover, S. M. (2004). Effects of injury to the suspensory apparatus, exercise, and horseshoe characteristics on the risk of lateral condylar fracture and suspensory apparatus failure in forelimbs of Thoroughbred racehorses. *American Journal of Veterinary Research*, *65*(11), 1508-1517.

Hill, R. C., Fox, L. E., Lewis, D. D., Beale, K. M., Nachreiner, R. F., Scott, K. C., Sundstrom, D. A., Jones, G. L., & Butterwick, R. F. (2001). Effects of racing and training on serum thyroid hormone concentrations in racing Greyhounds. *American Journal of Veterinary Research*, *62*(12), 1969-1972.

Hinchcliff, K. W., & Geor, R. J. (2008). The horse as an athlete: a physiological overview. In A. J. K. K.W. Hinchcliff, R.J. Geor (Ed.), *Equine exercise physiology: the science of exercise in the athletic horse* (Vol. 454, pp. 2-11). Elsevier Health Sciences, Edinburgh, Scotland.

Hitchens, P., Morrice-West, A., Stevenson, M., & Whitton, R. (2019). Meta-analysis of risk factors for racehorse catastrophic musculoskeletal injury in flat racing. *The Veterinary Journal*, *245*, 29-40.

Hitchens, P. L., Pivonka, P., Malekipour, F., & Whitton, R. C. (2018). Mathematical modelling of bone adaptation of the metacarpal subchondral bone in racehorses. *Biomechanics and Modeling in Mechanobiology, 17,* 877-890.

Holmes, J., Mirams, M., Mackie, E., & Whitton, R. (2014). Thoroughbred horses in race training have lower levels of subchondral bone remodelling in highly loaded regions of the distal metacarpus compared to horses resting from training. *The Veterinary Journal*, *202*(3), 443-447.

Holt, D., Northrop, A., Owen, A., Martin, J., & Hobbs, S. J. (2014). Use of surface testing devices to identify potential risk factors for synthetic equestrian surfaces. *Procedia Engineering, 72,* 949-954.

Hossain, M. I. (2020). *Modelling and simulation of multiple galloping quadrupedal dynamics* [Master's thesis, University of Technology Sydney]. OPUS: Open Publications of UTS Scholars. http://hdl.handle.net/10453/142516

Hossain, M. I., Eager, D., & Walker, P. (2019). Simulation of racing greyhound kinematics. *Proceedings of the SIMULTECH 2019 - 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (pp 47 – 56), Prague, Czech Republic.

Hossain, M. I., Eager, D., & Walker, P. D. (2020). Greyhound racing ideal trajectory path generation for straight to bend based on jerk rate minimization. *Scientific Reports, 10*(1), 1-15.

Hudson, P. E., Corr, S. A., & Wilson, A. M. (2012). High speed galloping in the cheetah (Acinonyx jubatus) and the racing greyhound (Canis familiaris): spatio-temporal and kinetic characteristics. *Journal of Experimental Biology*, *215*(14), 2425-2434.

Hulme, A., & Finch, C. F. (2015). From monocausality to systems thinking: a complementary and alternative conceptual approach for better understanding the development and prevention of sports injury. *Injury Epidemiology*, *2*, 1-12.

Hyttinen, M. M., Holopainen, J., Rene van Weeren, P., Firth, E. C., Helminen, H. J., & Brama, P. A. (2009). Changes in collagen fibril network organization and proteoglycan distribution in equine articular cartilage during maturation and growth. *Journal of Anatomy*, *215*(5), 584-591.

Iddon, J., Lockyer, R., & Frean, S. (2014). The effect of season and track condition on injury rate in racing greyhounds. *Journal of Small Animal Practice*, *55*(8), 399-404.

IER. (2018). *Size and scope of the New Zealand racing industry*.New Zealand Racing Board. https://www.rita.org.nz/sites/default/files/documents/NZ%20Racing%20Size%20and%20Scope%202018%20Full%20Report.pdf

Ilkiw, J., Davis, P., & Church, D. (1989). Hematologic, biochemical, blood-gas, and acid-base values in greyhounds before and after exercise. *American Journal of Veterinary Research*, *50*(4), 583-586.

Inkilä, L., Hyytiäinen, H. K., Hielm-Björkman, A., Junnila, J., Bergh, A., & Boström, A. (2022a). Part I of finnish agility dog survey: training and management of competition-level agility dogs. *Animals*, *12*(2), 212.

Inkilä, L., Hyytiäinen, H. K., Hielm-Björkman, A., Junnila, J., Bergh, A., & Boström, A. (2022b). Part II of finnish agility dog survey: agility-related injuries and risk factors for injury in competition-level agility dogs. *Animals*, *12*(3), 227.

Innes, J. F., & Clegg, P. (2010). Comparative rheumatology: what can be learnt from naturally occurring musculoskeletal disorders in domestic animals? *Rheumatology*, *49*(6), 1030-1039.

Ireland, B. (1998). Race track biomechanics and design. In M. Bloomberg, J. Dee, & R. Taylor (Eds.), *Canine Sports Medicine and Surgery* (pp. 391-396). W.B. Saunders Company, Philadelphia, United States of America.

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

Jeffrey, J. E., Gregory, D. W., & Aspden, R. M. (1995). Matrix damage and chondrocyte viability following a single impact load on articular-cartilage. *Archives of Biochemistry and Biophysics*, *322*(1), 87-96.

Johnson, K., Muir, P., Nicoll, R., & Roush, J. (2000). Asymmetric adaptive modeling of central tarsal bones in racing greyhounds. *Bone*, *27*(2), 257-263.

Johnson, K. A., Skinner, G. A., & Muir, P. (2001). Site-specific adaptive remodeling of Greyhound metacarpal cortical bone subjected to asymmetrical cyclic loading. *American Journal of Veterinary Research*, *62*(5), 787-793.

Jones, T. L., Baxter, M., & Khanduja, V. (2013). A quick guide to survey research. *The Annals of The Royal College of Surgeons of England*, *95*(1), 5-7.

Kai, M., Takahashi, T., Aoki, O., & Oki, H. (1999). Influence of rough track surfaces on components of vertical forces in cantering thoroughbred horses. *Equine Veterinary Journal*, *31*(S30), 214-217.

Kalkhoven, J. T., Watsford, M. L., & Impellizzeri, F. M. (2020). A conceptual model and detailed framework for stress-related, strain-related, and overuse athletic injury. *Journal of Science and Medicine in Sport*, *23*(8), 726-734.

Kasashima, Y., Smith, R., Birch, H., Takahashi, T., Kusano, K., & Goodship, A. (2002). Exercise-induced tendon hypertrophy: cross-sectional area changes during growth are influenced by exercise. *Equine Veterinary Journal*, *34*(S34), 264-268.

Kawcak, C. E., McIlwraith, C. W., & Firth, E. C. (2010). Effects of early exercise on metacarpophalangeal joints in horses. *American Journal of Veterinary Research*, *71*(4), 405-411.

Kesl, L. D. (1993). *The effects of sprint training regimens and sodium bicarbonate loading on muscle glycolysis, lactate accumulation, acid-base balance, and performance in the racing greyhound* [Doctoral dissertation, Iowa State University]. Retrospective Theses and Dissertations. 10666. https://lib.dr.iastate.edu/rtd/10666/.

Kesl, L. D., & Engen, R. L. (1998). Effects of NaHCO3 loading on acid-base balance, lactate concentration, and performance in racing greyhounds. *Journal of Applied Physiology*, *85*(3), 1037-1043.

Kibler, W., Chandler, T. J., & Stracener, E. S. (1992). Musculoskeletal adaptations and injuries due to overtraining. *Exercise and Sport Sciences Reviews*, *20*, 99-126.

Kim, W., Kawcak, C. E., McIlwraith, C. W., Firth, E. C., McArdle, B. H., & Broom, N. D. (2009). Influence of early conditioning exercise on the development of gross cartilage defects and swelling behavior of cartilage extracellular matrix in the equine midcarpal joint. *American Journal of Veterinary Research*, *70*(5), 589-598.

Kiviranta, I., Tammi, M., Jurvelin, J., Arokoski, J., Säämänen, A.-M., & Helminen, H. J. (1992). Articular cartilage thickness and glycosaminoglycan distribution in the canine knee joint after strenuous running exercise. *Clinical Orthopaedics and Related Research (1976-2007)*, *283*, 302-308.

Kiviranta, I., Tammi, M., Jurvelin, J., Säämänen, A. M., & Helminen, H. J. (1988). Moderate running exercise augments glycosaminoglycans and thickness of articular cartilage in the knee joint of young beagle dogs. *Journal of Orthopaedic Research*, *6*(2), 188-195.

Lacombe, V. A., Hinchcliff, K. W., Kohn, C. W., Devor, S. T., & Taylor, L. E. (2004). Effects of feeding meals with various soluble-carbohydrate content on muscle glycogen synthesis after exercise in horses. *American Journal of Veterinary Research*, *65*(7), 916-923.

Lacy, R. C. (1997). Importance of genetic variation to the viability of mammalian populations. *Journal of Mammalogy*, *78*(2), 320-335.

Langelier, E., & Buschmann, M. D. (2003). Increasing strain and strain rate strengthen transient stiffness but weaken the response to subsequent compression for articular cartilage in unconfined compression. *Journal of Biomechanics, 36*(6), 853-859.

Lanyon, L. E. (1992). Control of bone architecture by functional load bearing. *Journal of Bone and Mineral Research*, *7*(S2), S369-S375.

Lash, T., VanderWeele, T., Haneuse, S., & Rothman, K. (2020) *Modern Epidemiology*. Wolters Kluwer New York, USA.

Lassen, E., Craig, A. M., & Blythe, L. (1986). Effects of racing on hematologic and serum biochemical values in greyhounds. *Journal of the American Veterinary Medical Association*, *188*(11), 1299-1303.

Latkin, C. A., Edwards, C., Davey-Rothwell, M. A., & Tobin, K. E. (2017). The relationship between social desirability bias and self-reports of health, substance use, and social network factors among urban substance users in Baltimore, Maryland. *Addictive Behaviors*, *73*, 133-136.

Legg, K., Gee, E., Bolwell, C., Bridges, J., & Rogers, C. W. (2020). A Cross-Sectional Survey of the Training and Management of a Cohort of 2-Year-Old Standardbred Racehorses in New Zealand. *Journal of Equine Veterinary Science*, *87*, 102936.

Legg, K. A., Gee, E. K., Breheny, M., Gibson, M. J., & Rogers, C. W. (2023). A Bioeconomic Model for the Thoroughbred Racing Industry—Optimisation of the Production Cycle with a Horse Centric Welfare Perspective. *Animals*, *13*(3), 479.

Legg, K. A., Gee, E. K., Cochrane, D. J., & Rogers, C. W. (2021). Preliminary Examination of the Biological and Industry Constraints on the Structure and Pattern of Thoroughbred Racing in New Zealand over Thirteen Seasons: 2005/06–2017/18. *Animals*, *11*(10), 2807.

Lindholm, A., & Saltin, B. (1974). The physiological and biochemical response of Standardbred horses to exercise of varying speed and duration. *Acta Veterinaria Scandinavica*, *15*, 310-324.

Lipscomb, V., Lawes, T., Goodship, A., & Muir, P. (2001). Asymmetric densitometric and mechanical adaptation of the left fifth metacarpal bone in racing greyhounds. *Veterinary Record*, *148*(10), 308-311.

Lonsdale, R. A., Labuc, R. H., & Robertson, I. D. (1998). Echocardiographic parameters in training compared with non-training Greyhounds. *Veterinary Radiology & Ultrasound*, *39*(4), 325-330.

Lynch, M. E., Main, R. P., Xu, Q., Schmicker, T. L., Schaffler, M. B., Wright, T. M., & van der Meulen, M. C. (2011). Tibial compression is anabolic in the adult mouse skeleton despite reduced responsiveness with aging. *Bone*, *49*(3), 439-446.

Mactaggart, G., Waran, N., & Phillips, C. J. (2021). Identification of thoroughbred racehorse welfare issues by industry stakeholders. *Animals*, *11*(5), 1358.

Mahaffey, C. A., Peterson, M., & McIlwraith, C. W. (2012). Archetypes in Thoroughbred dirt racetracks regarding track design, clay mineralogy, and climate. *Sports Engineering*, *15*, 21-27.

Mahdavi, F., Hossain, M. I., Hayati, H., Eager, D., & Kennedy, P. (2018). Track shape, resulting dynamics and injury rates of greyhounds. *Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition*. *Volume 13: Design, Reliability, Safety, and Risk*. Pittsburgh, Pennsylvania, USA. The American Society of Mechanical Engineers.

Mahmood, H., Shepherd, D. E., & Espino, D. M. (2018). Surface damage of bovine articular cartilage-off-bone: the effect of variations in underlying substrate and frequency. *BMC Musculoskeletal Disorders*, *19*(1), 1-11.

Markwell, K., Firth, T., & Hing, N. (2017). Blood on the race track: An analysis of ethical concerns regarding animal-based gambling. *Annals of Leisure Research*, *20*(5), 594-609.

Marlin, D., & Nankervis, K. J. (2002). *Equine exercise physiology*. Blackwell Science Ltd, Oxford, UK.

Maroudas, A., Palla, G., & Gilav, E. (1992). Racemization of aspartic acid in human articular cartilage. *Connective Tissue Research*, *28*(3), 161-169.

Martig, S., Chen, W., Lee, P., & Whitton, R. (2014). Bone fatigue and its implications for injuries in racehorses. *Equine Veterinary Journal*, *46*(4), 408-415.

Martig, S., Hitchens, P. L., Lee, P. V., & Whitton, R. C. (2020). The relationship between microstructure, stiffness and compressive fatigue life of equine subchondral bone. *Journal of the Mechanical Behavior of Biomedical Materials*, *101*, 103439.

Martig, S., Lee, P. V., Anderson, G. A., & Whitton, R. C. (2013). Compressive fatigue life of subchondral bone of the metacarpal condyle in thoroughbred racehorses. *Bone*, *57*(2), 392-398.

McGivney, B. A., Han, H., Corduff, L. R., Katz, L. M., Tozaki, T., MacHugh, D. E., & Hill, E. W. (2020). Genomic inbreeding trends, influential sire lines and selection in the global Thoroughbred horse population. *Scientific Reports*, *10*(1), 466.

McHugh, M. (2016). *Special commission of inquiry into the greyhound racing industry in New South Wales*: *Volume 1*. Government of New South Wales. https://apo.org.au/sites/default/files/resource-files/2016-07/apo-nid65365_6.pdf.

McNicholl, J., Howarth, G., S, & Hazel, S., J. (2016). Influence of the Environment on Body Temperature of Racing Greyhounds. *Frontiers in Veterinary Science, 3 (53)*, 1-13.

Meldrum-Hana, C. (2015) *Making a killing*. ABC News: Four Corners. Retrieved on 11 August 2024 from https://www.abc.net.au/news/2015-02-17/making-a-killing/6127124.

Meeuwisse, W. H. (1994). Assessing causation in sport injury: a multifactorial model. *Clinical Journal of Sport Medicine*, *4*(3), 166-170.

Meeuwisse, W. H., Tyreman, H., Hagel, B., & Emery, C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine*, *17*(3), 215-219.

Mienaltowski, M. J., Huang, L., Stromberg, A. J., & MacLeod, J. N. (2008). Differential gene expression associated with postnatal equine articular cartilage maturation. *BMC Musculoskeletal Disorders*, *9*, 1-14.

Moffat, P., Firth, E. C., Rogers, C. W., Smith, R. K., Barneveld, A., Goodship, A. E., Kawcak, C. E., McIlwraith, C. W., & van Weeren, P. R. (2008). The influence of exercise during growth on ultrasonographic parameters of the superficial digital flexor tendon of young Thoroughbred horses. *Equine Veterinary Journal*, *40*(2), 136-140.

More, S. (1999). A longitudinal study of racing Thoroughbreds: performance during the first years of racing. *Australian Veterinary Journal*, *77*(2), 105-112.

Mori, S., & Burr, D. (1993). Increased intracortical remodeling following fatigue damage. *Bone*, *14*(2), 103-109.

Morrice-West, A. (2020). *An investigation of training and racing workloads in thoroughbred racehorses in Australia and their relationship to performance and bone fatigue* [Doctoral dissertation, University of Melbourne].Minerva Access. http://hdl.handle.net/11343/251323.

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Tasker, K., Lim, S. L., Smith, A. D., & Whitton, R. C. (2022). Relationship between Thoroughbred workloads in racing and the fatigue life of equine subchondral bone. *Scientific Reports*, *12*(1), 11528.

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Wong, A. S., & Whitton, R. C. (2021). Association of Thoroughbred Racehorse Workloads and Rest Practices with Trainer Success. *Animals*, *11*(11), 3130.

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

Morrice-West, A. V., Hitchens, P. L., Walmsley, E. A., Stevenson, M. A., Wong, A. S., & Whitton, R. C. (2021). Variation in GPS and accelerometer recorded velocity and stride parameters of galloping Thoroughbred horses. *Equine Veterinary Journal*, *53*(5), 1063-1074.

Muir, P., Johnson, K., & Ruaux-Mason, C. (1999). In vivo matrix microdamage in a naturally occurring canine fatigue fracture. *Bone*, *25*(5), 571-576.

Muir, P., Peterson, A., Sample, S., Scollay, M., Markel, M., & Kalscheur, V. (2008). Exercise-induced metacarpophalangeal joint adaptation in the Thoroughbred racehorse. *Journal of Anatomy, 213*(6), 706-717.

Murray, B., & Rosenbloom, C. (2018). Fundamentals of glycogen metabolism for coaches and athletes. *Nutrition Reviews*, *76*(4), 243-259.

Neuhaus, D., Fedde, M., & Gaehtgens, P. (1992). Changes in haemorheology in the racing greyhound as related to oxygen delivery. *European Journal of Applied Physiology and Occupational Physiology*, *65*, 278-285.

Nevill, M. E., Boobis, L. H., Brooks, S., & Williams, C. (1989). Effect of training on muscle metabolism during treadmill sprinting. *Journal of Applied Physiology*, *67*(6), 2376-2382.

Nicholson, C., & Firth, E. (2010). Assessment of bone response to conditioning exercise in the radius and tibia of young thoroughbred horses using pQCT. *Journal of Musculoskeletal & Neuronal Interactions*, *10*(3), 199-206.

Nold, J., Peterson, L., & Fedde, M. (1991). Physiological changes in the running greyhound (Canis domesticus): influence of race length. *Comparative Biochemistry and Physiology. Part A: Comparative Physiology*, *100*(3), 623-627.

Nugent, G. E., Law, A. W., Wong, E. G., Temple, M. M., Bae, W. C., Chen, A. C., Kawcak, C. E., & Sah, R. L. (2004). Site-and exercise-related variation in structure and function of cartilage from equine distal metacarpal condyle. *Osteoarthritis and Cartilage*, *12*(10), 826-833.

Nunamaker, D., Butterweck, D., & Provost, M. (1990). Fatigue fractures in thoroughbred racehorses: relationships with age, peak bone strain, and training. *Journal of Orthopaedic Research*, *8*(4), 604-611.

O'Neill, D., Church, D., McGreevy, P., Thomson, P., & Brodbelt, D. (2013). Longevity and mortality of owned dogs in England. *The Veterinary Journal*, *198*(3), 638-643.

O'Neill, D. G., Rooney, N. J., Brock, C., Church, D. B., Brodbelt, D. C., & Pegram, C. (2019). Greyhounds under general veterinary care in the UK during 2016: demography and common disorders. *Canine Genetics and Epidemiology*, *6*(1), 1-11.

Orlando, L., & Librado, P. (2019). Origin and evolution of deleterious mutations in horses. *Genes*, *10*(9), 649.

Özen, D., Kaya, U., Özen, H., Ambarcioğlu, P., Ünal, N., & Gürcan, İ. S. (2021). Investigation of Factors Influencing Thoroughbred Horses' Racing Career Length in Turkey. *Journal of Equine Veterinary Science*, *107*, 103782.

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

Parkin, T., Clegg, P., French, N., Proudman, C., Riggs, C., Singer, E., Webbon, P., & Morgan, K. (2005). Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. *Equine Veterinary Journal*, *37*(3), 192-199.

Parkin, T., French, N., Riggs, C., Morgan, K., Clegg, P., Proudman, C., Singer, E., & Webbon, P. (2004b). Risk of fatal distal limb fractures among thoroughbreds involved in the five tpes of racing in the United Kingdom. *Veterinary Record*, *154*(16), 493-497.

Parkin, T., & Rossdale, P. (2006). Epidemiology of equine performance wastage: importance of analysing facts and implementing their message in management. *Equine Veterinary Journal*, *38*(2), 98-100.

Parkin, T. D. (2008). Epidemiology of racetrack injuries in racehorses. *Veterinary Clinics of North America: Equine Practice*, *24*(1), 1-19.

Parry, D., Barnes, G., & Craig, A. (1978). A comparison of the size distribution of collagen fibrils in connective tissues as a function of age and a possible relation between fibril size distribution and mechanical properties. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, *203*(1152), 305-321.

Patterson-Kane, J., Parry, D., Birch, H., Goodship, A., & Firth, E. (1997). An age-related study of morphology and cross-link composition of collagen fibrils in the digital flexor tendons of young thoroughbred horses. *Connective Tissue Research*, *36*(3), 253-260.

Paulhus, D. L. (1984). Two-component models of socially desirable responding. *Journal of Personality and Social Psychology*, *46*(3), 598.

Payne, R., Hutchinson, J., Robilliard, J., Smith, N., & Wilson, A. (2005). Functional specialisation of pelvic limb anatomy in horses (Equus caballus). *Journal of Anatomy*, *206*(6), 557-574.

Pellegrino, F. J., Risso, A., Vaquero, P. G., & Corrada, Y. A. (2018). Physiological parameter values in greyhounds before and after high-intensity exercise. *Open Veterinary Journal*, *8*(1), 64-67.

Perkins, N., Reid, S., & Morris, R. (2004a). Effect of training location and time period on racehorse performance in New Zealand. 1. Descriptive analysis. *New Zealand Veterinary Journal*, *52*(5), 236-242.

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

Perkins, N., Reid, S., & Morris, R. (2005b). Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *New Zealand Veterinary Journal*, *53*(1), 69-76.

Perkins, N., Reid, S., & Morris, R. (2005c). Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 184-192.

Perkins, N., Reid, S., & Morris, R. (2005d). Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 171-183.

Perkins, N., Rogers, C., Firth, E., & Anderson, B. (2004b). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 3. In vivo ultrasonographic assessment of the cross-sectional area and echogenicity of the superficial digital flexor tendon. *New Zealand Veterinary Journal*, *52*(5), 280-284.

Perkins, N. R. (2005). *Epidemiology of health and performance in New Zealand racehorses: a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Veterinary Epidemiology at Massey University, Palmerston North, New Zealand* [Doctoral dissertation, Massey University]. Massey Research Online. http://hdl.handle.net/10179/1580.

Persson, S. (1968). Blood volume, state of training and working capacity of race horses. *Equine Veterinary Journal*, *1*(2), 52-62.

Petersen, J. L., Mickelson, J. R., Rendahl, A. K., Valberg, S. J., Andersson, L. S., Axelsson, J., Bailey, E., Bannasch, D., Binns, M. M., & Borges, A. S. (2013). Genome-wide analysis reveals selection for important traits in domestic horse breeds. *PLoS Genetics*, *9*(1), e1003211.

Peterson, M., & McIlwraith, C. (2008). Effect of track maintenance on mechanical properties of a dirt racetrack: a preliminary study. *Equine Veterinary Journal*, *40*(6), 602-605.

Physick-Sheard, P. (1986). Career profile of the Canadian Standardbred. I. Influence of age, gait and sex upon chances of racing. *Canadian Journal of Veterinary Research*, *50*(4), 449.

Pieschl, R. L., Toll, P., Leith, D., Peterson, L., & Fedde, M. (1992). Acid-base changes in the running greyhound: contributing variables. *Journal of Applied Physiology*, *73*(6), 2297-2304.

Pool, R. R., & Meagher, D. M. (1990). Pathologic findings and pathogenesis of racetrack injuries. *Veterinary Clinics of North America: Equine Practice*, *6*(1), 1-30.

Poulter, D. (1991). Greyhound injuries. *Acupuncture in Medicine*, *9*(1), 35-39.

Prole, J. (1976). A survey of racing injuries in the greyhound. *Journal of Small Animal Practice*, *17*(4), 207-218.

Pyne, D. B. (1994). Exercise-induced muscle damage and inflammation: a review. *Australian Journal of Science and Medicine in Sport*, *26*, 49-49.

Quinn, T., Allen, R., Schalet, B., Perumbuli, P., & Hunziker, E. (2001). Matrix and cell injury due to sub-impact loading of adult bovine articular cartilage explants: effects of strain rate and peak stress. *Journal of Orthopaedic Research*, *19*(2), 242-249.

Racing and Wagering Western Australia. (2022). *RWWA Rules of Greyhound Racing 2022*. Racing and Wagering Western Australia. Retrieved 29 August 2023 from https://www.rwwa.com.au/wp-content/uploads/2023/08/RWWA-GreyhoundRules-15-August-2023.pdf.

Ramzan, P. H., & Palmer, L. (2011). Musculoskeletal injuries in Thoroughbred racehorses: a study of three large training yards in Newmarket, UK (2005–2007). *The Veterinary Journal*, *187*(3), 325-329.

Ratzlaff, M. H., Hyde, M. L., Hutton, D. V., Rathgeber, R. A., & Balch, O. K. (1997). Interrelationships between moisture content of the track, dynamic properties of the track and the locomotor forces exerted by galloping horses. *Journal of Equine Veterinary Science*, *17*(1), 35-42.

Reed, S., Jackson, B., Mc Ilwraith, C., Wright, I., Pilsworth, R., Knapp, S., Wood, J., Price, J., & Verheyen, K. (2012). Descriptive epidemiology of joint injuries in Thoroughbred racehorses in training. *Equine Veterinary Journal*, *44*(1), 13-19.

Reed, S. R., Jackson, B. F., Wood, J. L., Price, J. S., & Verheyen, K. L. (2013). Exercise affects joint injury risk in young Thoroughbreds in training. *The Veterinary Journal*, *196*(3), 339-344.

Reynolds, A. J. (1992). *The effect of diet and training on energy substrate storage and utilization in sled dogs*. [Doctoral dissertation, Cornell University].

Rieppo, J., Hallikainen, J., Jurvelin, J. S., Kiviranta, I., Helminen, H. J., & Hyttinen, M. M. (2008). Practical considerations in the use of polarized light microscopy in the analysis of the collagen network in articular cartilage. *Microscopy Research and Technique*, *71*(4), 279-287.

Riggs, C. (2002). Fractures–a preventable hazard of racing thoroughbreds? *The Veterinary Journal*, *163*(1), 19-29.

Riggs, C., & Boyde, A. (1999). Effect of exercise on bone density in distal regions of the equine third metacarpal bone in 2-year-old Thoroughbreds. *Equine Veterinary Journal*, *31*(S30), 555-560.

Ringmark, S., Jansson, A., Lindholm, A., Hedenström, U., & Roepstorff, L. (2016). A 2.5 year study on health and locomotion symmetry in young Standardbred horses subjected to two levels of high intensity training distance. *The Veterinary Journal*, *207*, 99-104.

Rippe, J. M., Pape, L. A., Alpert, J. S., Ockene, I. S., Paraskos, J. A., Kotilainen, P., Anas, J., & Webster, W. (1982). Studies of systolic mechanics and diastolic behavior of the left ventricle in the trained racing greyhound. *Basic Research in Cardiology*, *77*(6), 619-644.

Rogers, C., & Firth, E. (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.

Rogers, C., Rivero, J., Van Breda, E., Lindner, A., & van Oldruitenborgh-Oosterbaan, M. S. (2007). Describing workload and scientific information on conditioning horses. *Equine and Comparative Exercise Physiology*, *4*(1), 1-6.

Rogers, C. W., Bolwell, C. F., & Gee, E. K. (2012a). Proactive management of the equine athlete. *Animals*, *2*(4), 640-655.

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.

Rogers, C. W., Bolwell, C. F., Gee, E. K., & Rosanowski, S. M. (2020). Equine musculoskeletal development and performance: impact of the production system and early training. *Animal Production Science*.

Rogers, C. W., Bolwell, C. F., Tanner, J. C., & van Weeren, P. R. (2012b). Early exercise in the horse. *Journal of Veterinary Behavior: Clinical Applications and Research*, *7*(6), 375-379.

Rogers, C. W., Firth, E. C., McIlwraith, C. W., Barneveld, A., Goodship, A. E., Kawcak, C. E., Smith, R. K., & van Weeren, P. R. (2008a). Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2-and 3-year-old racing careers. *Equine Veterinary Journal*, *40*(2), 119-127.

Rogers, C. W., Firth, E. C., McIlwraith, C. W., Barneveld, A., Goodship, A. E., Kawcak, C. E., Smith, R. K., & van Weeren, P. R. (2008b). Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine Veterinary Journal*, *40*(2), 111-118.

Rogers, C. W., Gee, E. K., & Dittmer, K. E. (2021). Growth and bone development in the horse: When is a horse skeletally mature? *Animals, 11*(12)*,* 3402.

Rosanowski, S., Chang, Y., Stirk, A., & Verheyen, K. (2016). Descriptive epidemiology of veterinary events in flat racing Thoroughbreds in Great Britain (2000 to 2013). *Equine Veterinary Journal*, *49*(3), 275-281.

Rosanowski, S., Chang, Y., Stirk, A., & Verheyen, K. (2017a). Descriptive epidemiology of veterinary events in flat racing Thoroughbreds in Great Britain (2000 to 2013). *Equine Veterinary Journal*, *49*(3), 275-281.

Rosanowski, S., Chang, Y., Stirk, A., & Verheyen, K. (2017b). Risk factors for race-day fatality, distal limb fracture and epistaxis in Thoroughbreds racing on all-weather surfaces in Great Britain (2000 to 2013). *Preventive Veterinary Medicine*, *148*, 58-65.

Rosanowski, S., Rogers, C., Bolwell, C., & Cogger, N. (2014). The movement pattern of horses around race meetings in New Zealand. *Animal Production Science*, *55*(8), 1075-1080.

Rose, R., & Bloomberg, M. (1989). Responses to sprint exercise in the greyhound: effects on haematology, serum biochemistry and muscle metabolites. *Research in Veterinary Science*, *47*(2), 212-218.

Rose, R., & Evans, D. (1990). Training horses-art or science? *Equine Veterinary Journal*, *22*(S9), 2-4.

Rovira, S., Muñoz, A., & Benito, M. (2007). Hematologic and biochemical changes during canine agility competitions. *Veterinary Clinical Pathology*, *36*(1), 30-35.

Sadeghi, H., Shepherd, D., & Espino, D. (2015). Effect of the variation of loading frequency on surface failure of bovine articular cartilage. *Osteoarthritis and Cartilage*, *23*(12), 2252-2258.

Schaaf, O. R., Eaton-Wells, R., & Mitchell, R. A. (2009). Biceps brachii and brachialis tendon of insertion injuries in eleven racing greyhounds. *Veterinary Surgery*, *38*(7), 825-833.

Schneider, H. P., Truex, R. C., & Knowles, J. O. (1964). Comparative observations of the hearts of mongrel and greyhound dogs. *The Anatomical Record*, *149*(2), 173-179.

Schneider, L. A., Delfabbro, P. H., & Burns, N. R. (2012). The influence of cerebral lateralisation on the behaviour of the racing greyhound. *Applied Animal Behaviour Science*, *141*(1-2), 57-64.

Schoning, P. (1995). Endocardiosis and other heart disease in greyhounds. *Journal of Veterinary Medicine Series A, 42*(1-10), 99-104.

Schoning, P., Erickson, H., & Milliken, G. (1995). Body weight, heart weight, and heart-to-body weight ratio in greyhounds. *American Journal of Veterinary Research*, *56*(4), 420-422.

Sedgwick, P. (2014). Retrospective cohort studies: advantages and disadvantages. *British Medical Journal,* 348: g1072.

Seeman, E. (2009). Bone modeling and remodeling. *Critical Reviews™ in Eukaryotic Gene Expression*, *19*(3), 219-233.

Setterbo, J., Fyhrie, P., Hubbard, M., Upadhyaya, S., & Stover, S. (2013). Dynamic properties of a dirt and a synthetic equine racetrack surface measured by a track-testing device. *Equine Veterinary Journal*, *45*(1), 25-30.

Setterbo, J. J., Yamaguchi, A., Hubbard, M., Upadhyaya, S. K., & Stover, S. M. (2011). Effects of equine racetrack surface type, depth, boundary area, and harrowing on dynamic surface properties measured using a track-testing device in a laboratory setting. *Sports Engineering*, *14*, 119-137.

Sharman, P., & Wilson, A. J. (2023). Genetic improvement of speed across distance categories in thoroughbred racehorses in Great Britain. *Heredity*, 131(1), 79-85.

Shearman, J., & Hopkins, W. (1996). Training of Standardbed maiden pacers. *Journal of Equine Veterinary Science*, *16*(3), 116-119.

Shiel, R. E., Brennan, S. F., O'Rourke, L. G., McCullough, M., & Mooney, C. T. (2007). Hematologic values in young pretraining healthy Greyhounds. *Veterinary Clinical Pathology*, *36*(3), 274-277.

Shrestha, K., Gilkerson, J. R., Stevenson, M. A., & Flash, M. L. (2021). Drivers of exit and outcomes for Thoroughbred racehorses participating in the 2017–2018 Australian racing season. *PloS One*, *16*(9), e0257581.

Sicard, G., Short, K., & Manley, P. (1999). A survey of injuries at five greyhound racing tracks. *Journal of Small Animal Practice*, *40*(9), 428-432.

Sjödin, B., Westing, Y. H., & Apple, F. S. (1990). Biochemical mechanisms for oxygen free radical formation during exercise. *Sports Medicine*, *10*(4), 236-254.

Smith, R. (1960). Radiological observations on the limbs of young greyhounds. *Journal of Small Animal Practice*, *1*(1-4), 84-90.

Smith, R., Birch, H., Goodman, S., Heinegård, D., & Goodship, A. (2002). The influence of ageing and exercise on tendon growth and degeneration—hypotheses for the initiation and prevention of strain-induced tendinopathies. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *133*(4), 1039-1050.

Smith, R., Zunino, L., Webbon, P., & Heinegård, D. (1997). The distribution of cartilage oligomeric matrix protein (COMP) in tendon and its variation with tendon site, age and load. *Matrix Biology*, *16*(5), 255-271.

Smith, R. K., & Goodship, A. E. (2008). The effect of early training and the adaptation and conditioning of skeletal tissues. *Veterinary Clinics of North America: Equine Practice*, *24*(1), 37-51.

Snow, D., Harris, R., & Stuttard, E. (1988). Changes in haematology and plasma biochemistry during maximal exercise in greyhounds. *The Veterinary Record*, *123*(19), 487-489.

Sobczynska, 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.

Soligard, T., Schwellnus, M., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T., Gleeson, M., Hägglund, M., & Hutchinson, M. R. (2016). How much is too much?(Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*, *50*(17), 1030-1041.

Sophia Fox, A. J., Bedi, A., & Rodeo, S. A. (2009). The basic science of articular cartilage: structure, composition, and function. *Sports Health*, *1*(6), 461-468.

Stafford, K. (2007). The welfare of the athletes; greyhounds and sled dogs. In K. Stafford, *The welfare of dogs* (pp. 143-160). Springer, Dordrecht, The Netherlands.

Steding, K., Engblom, H., Buhre, T., Carlsson, M., Mosén, H., Wohlfart, B., & Arheden, H. (2010). Relation between cardiac dimensions and peak oxygen uptake. *Journal of Cardiovascular Magnetic Resonance*, *12*(1), 1-9.

Steel, J., Taylor, R., Davis, P., Stewart, G., & Salmon, P. (1976). Relationships between heart score, heart weight and body weight in Greyhound dogs. *Australian Veterinary Journal*, *52*(12), 561-564.

Stepnik, M. W., Radtke, C. L., Scollay, M. C., Oshel, P. E., Albrecht, R. M., Santschi, E. M., Markel, M. D., & Muir, P. (2004). Scanning electron microscopic examination of third metacarpal/third metatarsal bone failure surfaces in thoroughbred racehorses with condylar fracture. *Veterinary Surgery*, *33*(1), 2-10.

Stevens, E. G., Baker, T., & Lewis, N. (2022). Dealing with sentient surplus: A moral economy of greyhound rehoming. *Environment and Planning E: Nature and Space*, *5*(4), 2033-2051.

Stevenson, M., Stafford, K., & Cave, N. (2009). *Risk factors for injury in New Zealand racing greyhounds*: *A report prepared for the New Zealand Racing Greyhound Association.* Massey University.

Stewart, I. B., & McKenzie, D. C. (2002). The human spleen during physiological stress. *Sports Medicine*, *32*, 361-369.

Stover, S. M., Johnson, B., Daft, B., Read, D., Anderson, M., Barr, B., Kinde, H., Moore, J., Stoltz, J., & Ardans, A. (1992). An association between complete and incomplete stress fractures of the humerus in racehorses. *Equine Veterinary Journal*, *24*(4), 260-263.

Strickler, T., Malone, T., & Garrett, W. E. (1990). The effects of passive warming on muscle injury. *The American Journal of Sports Medicine*, *18*(2), 141-145.

Sullivan, P., Evans, H., & McDonald, T. (1994). Platelet concentration and hemoglobin function in greyhounds. *Journal of the American Veterinary Medical Association*, *205*(6), 838-841.

Sun, T., Riggs, C., Cogger, N., Wright, J., & Al-Alawneh, J. (2018). Noncatastrophic and catastrophic fractures in racing Thoroughbreds at the Hong Kong Jockey Club. *Equine Veterinary Journal*, *51*(1), 77-82.

Sun, T. C. (2016). *Fracture incidence rates and the association of rest with bone remodelling in Thoroughbred racehorses at the Hong Kong Jockey Club* [Master's thesis, The University of Queensland], Queensland, Australia. UQ eSpace. https://doi.org/10.14264/uql.2016.986.

Swarbrick, C. (2021). *Chlöe Swarbrick: Greyhound racing is cruel, and we must end it now*. Stuff. https://www.stuff.co.nz/opinion/300284720/chle-swarbrick-greyhound-racing-is-cruel-and-we-must-end-it-now.

Symons, J., Hawkins, D., Fyhrie, D., Upadhyaya, S., & Stover, S. (2016). Modelling the interaction between racehorse limb and race surface. *Procedia Engineering, 147*, 175-180.

Tanase, M., Ambe, Y., Aoi, S., & Matsuno, F. (2015). A galloping quadruped model using left–right asymmetry in touchdown angles. *Journal of Biomechanics, 48*(12), 3383-3389.

Tanner, J., Rogers, C., Bolwell, C., & Gee, E. (2012). Preliminary examination of wastage in Thoroughbred and Standardbred horses in New Zealand using training milestones. *Proceedings of the New Zealand Society of Animal Production,* 72, (pp 172–174), Christchurch, New Zealand.

Tanner, J., Rogers, C., & Firth, E. (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.

Tanner, J., Rogers, C., & Firth, E. (2011). The relationship of training milestones with racing success in a population of Standardbred horses in New Zealand. *New Zealand Veterinary Journal*, *59*(6), 323-327.

Taoutaou, Z., Granier, P., Mercier, B., Mercier, J., Ahmaidi, S., & Prefaut, C. (1996). Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. *European Journal of Applied Physiology and Occupational Physiology*, *73*(5), 465-470.

Täubert, H., Agena, D., & Simianer, H. (2007). Genetic analysis of racing performance in Irish greyhounds. *Journal of Animal Breeding and Genetics*, *124*(3), 117-123.

Taylor, D. (1997). Bone maintenance and remodeling: a control system based on fatigue damage. *Journal of Orthopaedic Research*, *15*(4), 601-606.

Taylor, D. (1998). Fatigue of bone and bones: an analysis based on stressed volume. *Journal of Orthopaedic Research*, *16*(2), 163-169.

Taylor, D., Casolari, E., & Bignardi, C. (2004). Predicting stress fractures using a probabilistic model of damage, repair and adaptation. *Journal of Orthopaedic Research*, *22*(3), 487-494.

Thompson, L. (2003). *The dogs: a personal history of greyhound racing* (2nd ed.). High Stakes, London, United Kingdom.

Thomson, P., Hayek, A., Jones, B., Evans, D., & McGreevy, P. (2014). Number, causes and destinations of horses leaving the Australian Thoroughbred and Standardbred racing industries. *Australian Veterinary Journal, 92*(8), 303-311.

Thorpe, C., Clegg, P., & Birch, H. (2010). A review of tendon injury: why is the equine superficial digital flexor tendon most at risk? *Equine Veterinary Journal*, *42*(2), 174-180.

Tidswell, H., Innes, J., Avery, N., Clegg, P., Barr, A., Vaughan-Thomas, A., Wakley, G., & Tarlton, J. (2008). High-intensity exercise induces structural, compositional and metabolic changes in cuboidal bones—findings from an equine athlete model. *Bone*, *43*(4), 724-733.

Todd, E. T., Ho, S. Y., Thomson, P. C., Ang, R. A., Velie, B. D., & Hamilton, N. A. (2018). Founder-specific inbreeding depression affects racing performance in Thoroughbred horses. *Scientific Reports*, *8*(1), 6167.

Toll, P., Gaehtgens, P., Neuhaus, D., Pieschl, R., & Fedde, M. (1995). Fluid, electrolyte, and packed cell volume shifts in racing Greyhounds. *American Journal of Veterinary Research*, *56*(2), 227-232.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International*, *67*(3), 260-266.

Toniolo, L., Maccatrozzo, L., Patruno, M., Pavan, E., Caliaro, F., Rossi, R., Rinaldi, C., Canepari, M., Reggiani, C., & Mascarello, F. (2007). Fiber types in canine muscles: myosin isoform expression and functional characterization. *American Journal of Physiology-Cell Physiology*, *292*(5), C1915-C1926.

Usherwood, J. R., & Wilson, A. M. (2005). No force limit on greyhound sprint speed. *Nature*, *438*(7069), 753-754.

Vallance, S., Entwistle, R., Hitchens, P., Gardner, I., & Stover, S. M. (2013). Case–control study of high-speed exercise history of T horoughbred and Q uarter H orse racehorses that died related to a complete scapular fracture. *Equine Veterinary Journal*, *45*(3), 284-292.

Van den Hoogen, B. M., Van den Lest, C., Van Weeren, P., Van Golde, L., & Barneveld, A. (1999). Effect of exercise on the proteoglycan metabolism of articular cartilage in growing foals. *Equine Veterinary Journal*, *31*(S31), 62-66.

van Ginneken, M. M. E. (2006). *Adaptation of signal transduction and muscle proteome in trained horses* [Doctoral dissertation, Utrecht University]. http://igitur-archive.library.uu.nl/dissertations/2006-0324-200118/index.htm.

Van Weeren, P., & Barneveld, A. (1999). Introduction: Study design to evaluate the influence of exercise on the development of the musculoskeletal system of foals up to age 11 months. *Equine Veterinary Journal, 31*(S31), 4-8.

Van Weeren, P., Firth, E., Brommer, H., Hyttinen, M., Helminen, H., Rogers, C., Degroot, J., & Brama, P. (2008). Early exercise advances the maturation of glycosaminoglycans and collagen in the extracellular matrix of articular cartilage in the horse. *Equine Veterinary Journal*, *40*(2), 128-135.

Vaughan, L. (1969). Gracilis muscle injury in greyhounds. *Journal of Small Animal Practice*, *10*(6), 363-375.

Velie, B., Knight, P., Thomson, P., Wade, C., & Hamilton, N. (2013a). The association of age at first start with career length in the Australian Thoroughbred racehorse population. *Equine Veterinary Journal*, *45*(4), 410-413.

Velie, B., Stewart, B., Lam, K., Wade, C., & Hamilton, N. (2013b). Profiling the careers of Thoroughbred horses racing in Hong Kong between 2000 and 2010. *Equine Veterinary Journal*, *45*(6), 694-699.

Velie, B., Wade, C., & Hamilton, N. (2013c). Profiling the careers of Thoroughbred horses racing in Australia between 2000 and 2010. *Equine Veterinary Journal*, *45*(2), 182-186.

Verheyen, K., Henley, W., Price, J., & Wood, J. (2005). Training-related factors associated with dorsometacarpal disease in young Thoroughbred racehorses in the UK. *Equine Veterinary Journal*, *37*(5), 442-448.

Verheyen, K., Newton, J., Price, J., & Wood, J. (2006a). A case-control study of factors associated with pelvic and tibial stress fractures in Thoroughbred racehorses in training in the UK. *Preventive Veterinary Medicine*, *74*(1), 21-35.

Verheyen, K., Price, J., Lanyon, L., & Wood, J. (2006b). Exercise distance and speed affect the risk of fracture in racehorses. *Bone*, *39*(6), 1322-1330.

Verheyen, K., & Wood, J. (2004). Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine Veterinary Journal*, *36*(2), 167-173.

Verheyen, K. L., Price, J. S., & Wood, J. L. (2009). Exercise during training is associated with racing performance in Thoroughbreds. *The Veterinary Journal*, *181*(1), 43-47.

Verzijl, N., DeGroot, J., Thorpe, S. R., Bank, R. A., Shaw, J. N., Lyons, T. J., Bijlsma, J. W., Lafeber, F. P., Baynes, J. W., & TeKoppele, J. M. (2000). Effect of collagen turnover on the accumulation of advanced glycation end products. *Journal of Biological Chemistry*, *275*(50), 39027-39031.

Vogel, K., & Heinegård, D. (1985). Characterization of proteoglycans from adult bovine tendon. *Journal of Biological Chemistry*, *260*(16), 9298-9306.

Vogel, K. G., & Evanko, S. P. (1987). Proteoglycans of fetal bovine tendon. *Journal of Biological Chemistry*, *262*(28), 13607-13613.

Warden, S. J., Fuchs, R. K., Castillo, A. B., Nelson, I. R., & Turner, C. H. (2007). Exercise when young provides lifelong benefits to bone structure and strength. *Journal of Bone and Mineral Research*, *22*(2), 251-259.

Warden, S. J., Galley, M. R., Hurd, A. L., Wallace, J. M., Gallant, M. A., Richard, J. S., & George, L. A. (2013). Elevated mechanical loading when young provides lifelong benefits to cortical bone properties in female rats independent of a surgically induced menopause. *Endocrinology*, *154*(9), 3178-3187.

Warden, S. J., Hurst, J. A., Sanders, M. S., Turner, C. H., Burr, D. B., & Li, J. (2005). Bone adaptation to a mechanical loading program significantly increases skeletal fatigue resistance. *Journal of Bone and Mineral Research*, *20*(5), 809-816.

Warden, S. J., Roosa, S. M. M., Kersh, M. E., Hurd, A. L., Fleisig, G. S., Pandy, M. G., & Fuchs, R. K. (2014). Physical activity when young provides lifelong benefits to cortical bone size and strength in men. *Proceedings of the National Academy of Sciences*, *111*(14), 5337-5342.

Webb, H., Weston, J., Norman, E., Cogger, N., & Rogers, C. (2019). Experience, riding practices and training methods of Fédération Equestre Internationale (FEI: 80-160 km) level endurance horse rider-owner-trainers in New Zealand. *Comparative Exercise Physiology*, *15*(2), 137-145.

Webster, E. L., Hudson, P. E., & Channon, S. B. (2014). Comparative functional anatomy of the epaxial musculature of dogs (Canis familiaris) bred for sprinting vs. fighting. *Journal of Anatomy*, *225*(3), 317-327.

Wendelburg, K., Kaderly, R., Dee, L., & Eaton-Wells, R. (1988). Stress fractures of the acetabulum in 26 racing Greyhounds. *Veterinary Surgery*, *17*(3), 128-134.

Wentink, G. (1979). Dynamics of the hind limb at walk in horse and dog. *Anatomy and Embryology*, *155*, 179-190.

White, E., Hunt, J. R., & Casso, D. (1998). Exposure measurement in cohort studies: the challenges of prospective data collection. *Epidemiologic Reviews*, *20*(1), 43-56.

Whitton, R., Ayodele, B., Hitchens, P., & Mackie, E. (2018). Subchondral bone microdamage accumulation in distal metacarpus of Thoroughbred racehorses. *Equine Veterinary Journal*, *50*(6), 766-773.

Whitton, R. C., Mirams, M., Mackie, E. J., Anderson, G. A., & Seeman, E. (2013). Exercise-induced inhibition of remodelling is focally offset with fatigue fracture in racehorses. *Osteoporosis International*, *24*, 2043-2048.

Whitton, R. C., Trope, G. D., Ghasem-Zadeh, A., Anderson, G. A., Parkin, T. D., Mackie, E. J., & Seeman, E. (2010). Third metacarpal condylar fatigue fractures in equine athletes occur within previously modelled subchondral bone. *Bone*, *47*(4), 826-831.

Williams, S., Usherwood, J., Jespers, K., Channon, A., & Wilson, A. (2009). Exploring the mechanical basis for acceleration: pelvic limb locomotor function during accelerations in racing greyhounds (Canis familiaris). *Journal of Experimental Biology*, *212*(4), 550-565.

Williams, S., Wilson, A., Rhodes, L., Andrews, J., & Payne, R. (2008). Functional anatomy and muscle moment arms of the pelvic limb of an elite sprinting athlete: the racing greyhound (Canis familiaris). *Journal of Anatomy*, *213*(4), 361-372.

Wilsher, S., Allen, W., & Wood, J. (2006). Factors associated with failure of Thoroughbred horses to train and race. *Equine Veterinary Journal*, *38*(2), 113-118.

Windred, A., Osmotherly, P., & McGowan, C. M. (2007). Pre-race warm-up practices in Greyhound racing: a pilot study. *Equine and Comparative Exercise Physiology*, *4*(3-4), 119-122.

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.

Woo, S. L.-Y., Debski, R. E., Zeminski, J., Abramowitch, S. D., Chan Saw, M., Serena S, & Fenwick, J. A. (2000). Injury and repair of ligaments and tendons. *Annual Review of Biomedical Engineering*, *2*(1), 83-118.

Zarrinkalam, K., Kuliwaba, J., Martin, R., Wallwork, M., & Fazzalari, N. (2005). New insights into the propagation of fatigue damage in cortical bone using confocal microscopy and chelating fluorochromes. *European Journal of Morphology, 42,* 81-90.

Zerwekh, J. E., Ruml, L. A., Gottschalk, F., & Pak, C. Y. (1998). The effects of twelve weeks of bed rest on bone histology, biochemical markers of bone turnover, and calcium homeostasis in eleven normal subjects. *Journal of Bone and Mineral Research, 13*(10), 1594-1601.

PRELUDE TO CHAPTER 2

From Chapter 1 it was evident that there was a lack of published literature detailing career length and patterns of racing for greyhounds. Understanding the structure of the greyhound industry is an important step in determining factors that may contribute to the productivity and career length of racing greyhounds.

Chapter 2 therefore set out to quantify frequency of racing and career milestones in a cohort of racing greyhounds in New Zealand. The study utilised retrospective racing records to identify racing patterns and the career duration of greyhounds. During the analysis, I recognised that the New Zealand racing population is comprised of greyhounds that were whelped (born) in either New Zealand or Australia. The two sub-populations were compared to determine if there were any differences in the career profile depending on where the greyhound was whelped.

A version of this chapter has been previously published in Animals.

Palmer, A. L., Bolwell, C. F., Stafford, K. J., Gal, A., & Rogers, C. W. (2020). Patterns of racing and career duration of racing greyhounds in New Zealand. *Animals*, 10(5), 796.

Chapter 2 PATTERNS OF RACING AND CAREER DURATION OF RACING GREYHOUNDS IN NEW ZEALAND

2.1 SIMPLE SUMMARY

Despite welfare concerns associated with the sport of greyhound racing, there is limited information on the career length and patterns of racing for greyhounds. Performance outcomes, including number of racing starts, career length and the age at which greyhounds finish racing, provide insight into causes of attrition in the greyhound racing industry. To investigate trends in greyhound racing careers a baseline is required. This chapter presents results from a descriptive analysis exploring career duration and patterns of racing of greyhounds in New Zealand.

2.2 ABSTRACT

The welfare and wastage of racing greyhounds is a topic of public concern. Little is published about the racing patterns and career lengths of these dogs in New Zealand. The aim of this study is to describe the pattern of greyhound racing in New Zealand. Data on all race starts between 1 August 2011 and 25 March 2018 were supplied by Greyhound Racing New Zealand. A cohort was created containing dogs that had a racing career between 1 August 2013 and 31 July 2017. Data were collated within a customised Microsoft Access database from electronic records of all racing starts for every dog within the 2013-2016 racing seasons. For this cohort of racing dogs, there were 97,973 race starts across 22,277 races involving 2,393 individual greyhounds. The median number of days between racing starts was seven days (interquartile range (IQR): 4-10 days). The median career length was 424 days (IQR: 206-647 days) and the median number of racing starts throughout a racing career was 35 (IQR: 16-59 starts). Dogs of similar athletic ability, based on the maximum race grade reached during their career, finished racing at a similar age.

2.3 INTRODUCTION

In Australasia, there is public concern about the welfare of racing greyhounds (*Canis familiaris*) with particular focus on injury rates and the 'wastage' of greyhounds in the industry (Tan, 2018; Costelloe, 2019). Such concerns criticise the greyhound racing industry for exploiting the natural instincts of these sighthounds, in order to create a product, through gambling on a competition based on physical performance and speed (Markwell et al., 2017). Previous studies have reported descriptions of racing related injuries that occur in racing greyhounds (Sicard et al., 1999; Stevenson et al., 2009; Iddon et al., 2014). However, no studies have investigated patterns of racing and the impact of these on the racing careers of greyhounds; an essential step in recognising areas of potential welfare compromise.

Greyhound racing is one of the three animal racing codes in New Zealand, the other two being Thoroughbred and Standardbred horse racing. It has the lowest number of racing animals and annual financial turnover. The greyhound industry is estimated to contribute $92.6 million annually to the New Zealand economy (IER, 2018). Comparatively, the Thoroughbred industry contribute $1,098.9 million and the Harness industry $442.1 million to the New Zealand economy (IER, 2018). The availability of racing opportunities determines wagering turnover, the primary income stream in the industry (Tanner, 2011). However, racing opportunities may be impacted by the limits of a dog's physiological ability to maintain regular high-intensity racing and training regimes.

As part of normal race-day procedures, greyhounds travel to the racetrack and compete in fields against dogs with similar ability. The New Zealand greyhound racing scene is comprised of dogs that were born and registered in New Zealand, as well as dogs that were born and registered in Australia before being registered and raced in New Zealand. These two populations provide an opportunity to examine the impact of the pattern of New Zealand racing on dogs that may have previously raced within another jurisdiction, namely Australia.

The majority of work in racing industries, looking in particular at career length, wastage and injuries, has focused on horses, especially Thoroughbreds. In Thoroughbred racing, the pattern of racing and race training have been associated with increased risk for different injuries (Boston & Nunamaker, 2000; Tanner et al., 2016). Performance outcomes to quantify wastage in racehorses have included career length and number of lifetime racing starts (Sobczynska, 2007; Tanner et al., 2011, 2013; Velie et al., 2013a; Velie et al., 2013b). Injuries sustained by racing greyhounds have the potential to compromise an individual's welfare and pose a direct cost on the greyhound racing industry through lost racing days, expenses involved with treatments and losses due to early retirement from racing (Stevenson et al., 2009; Beer, 2014). There is very little published research surrounding the management, training and racing of greyhounds in New Zealand. Quantification of the current industry in New Zealand is necessary in order to provide insight into the potential causes of attrition of racing greyhounds in New Zealand.

The aim of this chapter was to describe the racing careers of greyhounds in New Zealand. This chapter presents career duration and pattern of racing data that will help identify potential factors that could shorten a dogs racing career or lead to wastage in the industry.

2.4 MATERIALS AND METHODS

Greyhound Racing New Zealand (GRNZ), the governing body for greyhound racing in New Zealand hold all the official records of the industry. They provided data containing details on all racing starts in New Zealand between 1 August 2011 and 25 March 2018. These data were used for descriptive analysis to investigate all greyhound racing starts from the seven greyhound racing tracks across New Zealand during four racing seasons. The original dataset contained and included: race date, racetrack, race number, race distance, race grade, field size and final placing. The race grade refers to the grade in which the dog was racing, where class 0 (C0) are maiden races, class 1 (C1) are lower grade races and there is a sequential increase to the higher-grade races until class 5 (C5). Dog level data were provided in a separate dataset, which contained information from all dogs registered for racing that were whelped (born) between 1 August 2009 to 30 November 2017. The data included: dog identity number, dog name, whelp date, dog sex, registration date, dog ear-brand tattoo, and first trial date. These data were imported into a customised Microsoft Access database. Using the race date and dog name information, new variables were created for race season, race year, number of racing starts per career, length of career in days, and number of days since previous race for each dog. The dog ear-brand tattoo code was used to create a new variable for the country, New Zealand or Australia, in which the dog was born. During analysis, the two sub-populations of dogs based on country of origin were compared to determine if there were any differences in the career profile depending on where the greyhound was whelped (born). The integrity of the data were checked using histograms and cross tabulation, where outliers or points of interest were compared with the official online GRNZ database.

For this study a cohort containing information on all dogs that started racing after 1st January 2013 and finished racing by 31st July 2017 was created. One of the selection criteria for eligibility was that the dogs had to be born after 1st July 2011. This date was 18 months before the first race date (1st January 2013) and at this time dogs were not permitted to be nominated for racing until they reach 14 months of age (Rule 19.10) (Greyhound Racing New Zealand, 2017). Data on all racing starts were provided through to 25th March 2018 and data from dogs with no racing records after 31st July 2017 were included as they were assumed to have finished their racing career. Information on the race history for the greyhounds born in Australia and imported to race in New Zealand were not available and only race starts in New Zealand were considered.

Descriptive statistics were used to describe the data at a population and at a cohort level and were carried out for the both dog-level and race-level variables. Racing milestones of interest included: age when first registered for racing, age at qualifying trial, age of first race start and age of the last recorded racing start. Normality of continuous data were assessed with the Shapiro-Wilk test and Pearson's Chi-squared tests. Continuous data that were non-normally distributed were summarised with medians and percentiles. Nominal data are presented as counts and percentages. Kruskal-Wallis tests and Wilcoxson rank-sum tests were used to compare the age at which racing milestones were achieved by the country in which the dog was born.

The stability of frequency of racing was established using an autocorrelation function applied to data recording the pattern of racing. The distribution of racing starts was explored by categorising the continuous variable of number of days between racing starts for each dog by quartiles thereby creating a categorical variable which contained 'high-intensity racing interval' (minimum to lower quartile: 1-4 days), 'medium-intensity racing interval' (interquartile range: 5-10 days) and 'low-intensity racing interval' (upper quartile to maximum: 11-539 days) dogs. The proportion of high-intensity racing intervals that occurred during a racing career was calculated for each dog, using the number of high-intensity racing intervals and the total number of racing starts. Length of racing career was measured as both the number of racing starts during a career and the number of days from the dog's first racing start through to the last recorded racing start. Kaplan-Meier survival analysis (Kaplan & Meier, 1958) was used to plot the age (months) of final race start, and to calculate the median age (months) and 95% confidence interval (CI) at final race start by country of origin. Differences in the median age at which dogs finished racing were investigated using a log-rank test. Cox regression analysis, using the Breslow method of handling ties, assessed the association between the proportions of high-inter-race intervals (adjusting for country of origin, sex of the dog, maximum race grade reached during career) and month started racing, on the outcome of final race age in months. Variables showing some univariate association ($p<0.2$) with the outcome were further evaluated in a multivariable model with each variable being sequentially removed from the full model in a backward stepwise fashion. Exposure variables were retained in the model if they significantly improved the model fit (likelihood ratio statistic p-value <0.05). Biologically plausible interaction terms between covariates were then considered for inclusion in the multivariable model if associated with a likelihood ratio test p-value <0.05. The proportional hazards assumption was tested through a statistical test to determine whether the Schoenfeld residuals are independent of time and through visual inspection of log-cumulative hazard plots and scaled Schoenfeld residuals plots (Dohoo et al., 2009). Model fit was visually assessed through plots of Cox-Snell residuals (Dohoo et al., 2009). However, given the interactions between these variables, the multivariable model was not further analysed. Given the complexity of the relationship amongst the predictor variables, the decision not to analyse the multivariable model was based on theoretical justification, as the interrelated variables did not provide unique contribution to the outcome and inclusion of these variables complicated the interpretation of results without enhancing the understanding of the underlying relationship. All statistical analyses were conducted in Stata 15 (StataCorp LP, College Station TX, USA) and R version 0.98.932 (R Development Core Team, 2014).

2.5 RESULTS

2.5.1 Population data

The analysed population consisted of 3,404 dogs (71%) registered as puppies in New Zealand and 1,403 (29%) registered in an Australian state and imported to New Zealand either before or during their racing career. Male dogs accounted for 54% (n = 2,609/4,807) of the dogs that raced. Data from the four racing seasons (2013-2016) contained 175,322 eligible racing starts by 4,807 individual dogs in 22,277 races. There were no significant differences across the racing seasons examined in the number of racing tracks (n = 7), the number of race meetings (median: 449, interquartile range (IQR): 449-450), number of races (median: 5,586, IQR: 5,525-5,614), number of racing starts (median: 43,923, IQR: 43,442-44,222), or number of individual greyhounds racing (median: 2,171, IOR: 2,123-2,205) across the racing seasons.

The pattern of racing remained consistent across the years, with more racing starts during winter (median: 11,496, IQR: 11,311-11,631) compared to spring (median: 10,853, IQR: 10,744-11,021), summer (median: 10,582, IQR: 10,400-10,865) and autumn (median: 10,838, IQR: 10,683-11,008). The number of races held remained consistent throughout winter (median: 1,457, IQR: 1,435-1,472), spring (median: 1,383, IQR: 1,368-1,402), summer (median: 1,354, IQR: 1,327-1,383) and autumn (median: 1,375, IQR: 1,358-1,395).

Meetings were located at seven racetracks in seven regions across the North and South Islands of New Zealand. There were significantly more racing starts in the Canterbury (median: 12,988, IQR: 12,945-13,102) and Whanganui (median: 10,594, IQR: 10,310 - 10,846) regions each season ($p < 0.05$), where more than one race meeting was held each week, compared to the other five racing tracks (Auckland: median: 5,821, IQR: 5,782-5,853; Waikato: median: 4,320, IQR: 4,219-4,395; Manawatu: median: 4,843, IQR: 4,769-4,997; Otago: median: 2,682, IQR: 2,671-2,699; Southland: median: 2,499, IQR: 2,415-2,577).

The majority of races (89%; n = 19,835/22,277) had a full field of eight dogs, and races with seven or more runners accounted for 98% (n = 21,891/22,277) of all races. The age of the dogs, at the time of any racing start, ranged from 14 months through to 67 months with a median racing age of 31 months for New Zealand born dogs and 34 months for Australian born dogs. From the 175,322 racing starts, 66% (n = 115,518/175,322) of starts were dogs aged between 14 and 36 months; and a total of 99.99% (n = 175,312/175,322) of racing starts were completed by dogs aged between 14 and 72 months.

The distribution of races throughout the race grades, stratified by the age of the dog at the time of the race, is presented in Table 2.1. Dogs began their racing career at the earliest age of 14 months and 47% (n = 82,834) of races were run by dogs aged between 24 and 36 months. Maiden races were comprised primarily of dogs 14-months to 25-months-old (64%), while the higher race classes (3, 4 and 5) were run by dogs predominantly older than 26 months of age (Table 2.1).

Table 2.1 The distribution (number and percentage) of greyhounds racing by age and racing class for the 2013-2016 racing seasons in New Zealand.

				Race Grade				
Age (month category)	**Class 0**	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Other** [a]	**No. of starters**
% dogs per grade								
14-25	64.1	27.8	15.7	11.4	7.6	5.8	23.5	43,428
26-31	22.3	26.3	24.8	25.2	22.7	21.5	32	43,455
32-38	9.7	21.7	25.9	29.2	32.3	35.6	23.2	42,087
39-79	3.9	24.2	33.6	34.3	37.4	37.1	21.3	46,352
No. of starters by grade								
	25,494	56,933	28,211	20,128	20,882	14,861	8,813	
No. of races by grade								
	3,235	7,246	3,575	2,555	2,653	1,866	1,147	
% races by grade								
	14.5	32.5	16	11.5	11.9	8.4	5.1	

[a] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies

The race distance ranged from 295 metres to 779 metres and races were categorised as sprint < 457 metres (n = 14,459, 65%), middle distance 457-599 metres (n = 7,404, 33%) or distance races ≥ 600 metres (n = 414, 2%). The median age of the dogs racing varied by the race distance category (p<0.001) (sprint: median: 32 months old, IQR: 26–40 months; middle distance: median: 31 months old, IQR: 25–38 months; distance: median: 37 months old, IQR: 31–43 months).

2.5.2 Cohort data

A cohort of 2,630 registered dogs had a racing career between 1st August 2013 and 31st July 2017. Of these, 1,718 dogs were born in New Zealand (65%) and 912 born in Australia (35%). In the cohort 54% of the dogs were male (n = 1,417/2,630) and 46% bitches (n = 1,213/2,630). Male dogs accounted for 61% (n=553/912) of the Australian born dogs and 50% (n = 864/1,718) of the New Zealand born dogs registered for racing. Of these 2,630 dogs registered for racing, 2,393 dogs (91%) had at least one race start and 237 dogs (9%) were registered but never raced. There were records for 2,117 qualifying trials which included 404 (19%) Australian dogs and 1,713 (81%) New Zealand dogs. Of the 2,393 dogs that raced; 675 (28%) were Australian dogs and 1,718 (72%) were New Zealand born dogs. The dogs that raced had a total of 97,973 starts in 21,571 races throughout the defined time period. Summary measures for the age dogs were registered for racing, completed their qualifying trial and completed their first racing start are presented in Table 2.2. There were significant differences between Australian and New Zealand dogs for the age they were registered, trialled and raced (p <0.001).

Table 2.2 Summary information for the age at which racing milestones were reached, as well as the time between registering, trialling and racing, for a cohort of New Zealand and Australian born greyhounds that raced in New Zealand during the 2013-2016 racing seasons. Differences between dogs from the two countries were tested with a Kruskal-Wallis test.

	Australian dogs	**New Zealand dogs**	**Total**	**p-value**
Age registered [a] *(months)*				
Median	24	19	20	<0.001
IQR	20-29	17-21	17-23	
n	912	1,718	2,630	
Age of qualifying trial [a] *(months)*				
Median	20	20	20	0.613
IQR	18-23	18-20	18-23	
n	404	1,713	2,117	
Age of first racing start [a] *(months)*				
Median	25	20	21	<0.001
IQR	21-30	18-23	19-25	
n	675	1,718	2,393	
Days between registering and racing				
Median	22	35	31	<0.001
IQR	13-45	19-71	17-64	
n	678	1,692	2,370	
Days between qualifying trial and racing				
Median	13	12	12	0.308
IQR	7-28	7-23	7-24	
n	364	1,693	2,057	
Age of last race (months)				
Median	39	36	37	<0.001
IQR	33-46	29-43	30-44	
n	675	1,718	2,393	

[a] The age racing milestones were reached in New Zealand.

The median number of days between racing starts for each dog was seven (IQR: 4-10). In 116 of 95,580 racing starts (0.1%), dogs raced on consecutive days and 5,451 (6%) competed in races two days apart. Most racing was structured around a seven-day cycle (Figure 2.1), regardless of the different regions and racing seasons.

The median did not change across different age groups based on the age of first racing start, nor did it change for the country where the dog was born. The autocorrelation function (ACF) plot (Figure 2.1b) represents the correlation in time between races where lag was set at seven days. There was a sharp reduction in the correlation coefficient between the reference of seven days (ACF=1.00) and lag 1 (ACF=0.085). The plot also shows decay in the correlation over a period of seven weeks with some irregularity after this point.

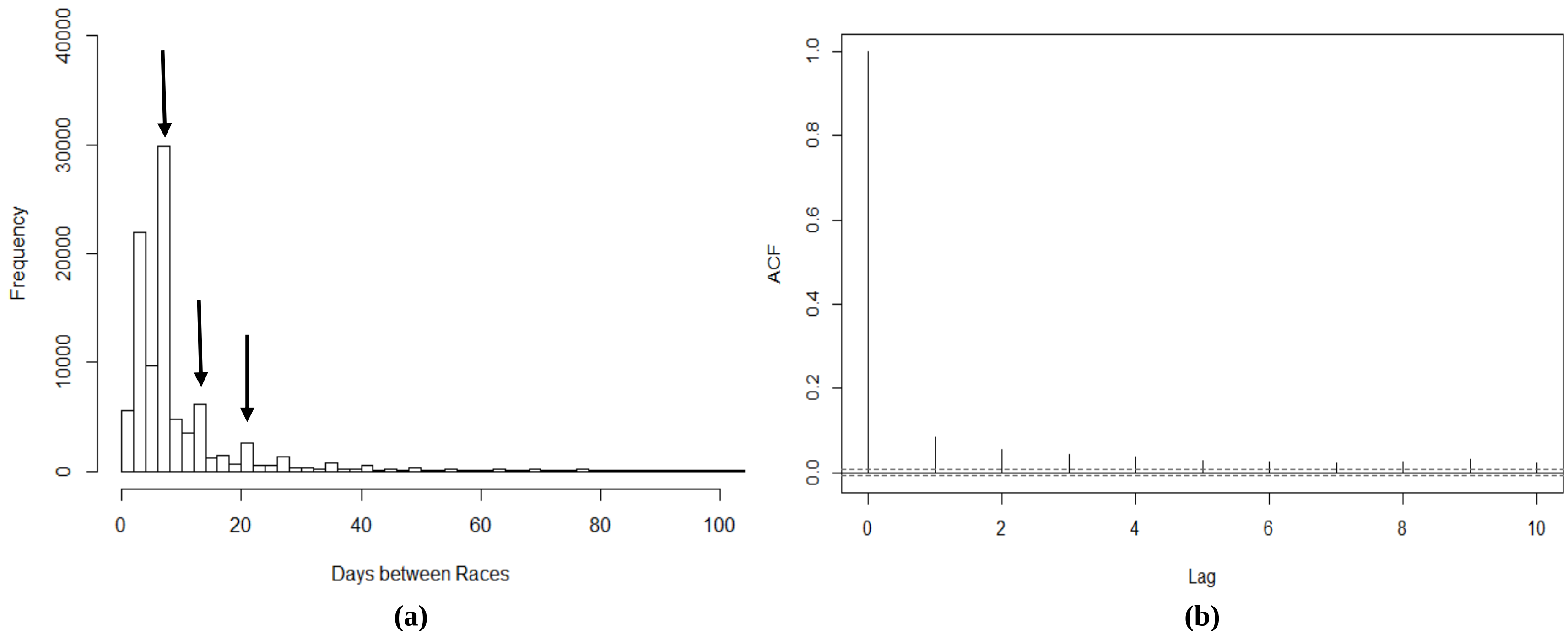


Figure 2.1 Frequency of racing, in terms of time between racing starts, in a cohort of 2,393 racing greyhounds followed across 95,580 racing starts between the 2013 and 2016 seasons: **(a)** Frequency histogram of the number of days between consecutive races for individual greyhounds. The highest 1% of values have been removed. The arrows above the histogram demonstrate the peaks at seven days, 14 days and 21 days respectively; (**b**) Autocorrelation function (ACF) showing the correlation in the raw residuals as a function of number of days between successive races for individual dogs. The dashed grey lines represent approximate two-sided critical bounds for the autocorrelation at $\alpha = 0.01$.

The median number of starts per racing career was 35 (IQR: 16–59) with no significant difference in the number of racing starts between the Australian (median: 33 starts, IQR: 16-55 starts) and New Zealand dogs (median: 35 starts, IQR: 16-59 starts) (p = 0.15). The median racing career length was 424 days (IQR: 206-647 days). There was a significant difference between the career length in days for Australian (median: 378 days, IQR: 183-583 days) and New Zealand (median: 445 days, IQR: 216-672 days) dogs (p <0.001). There was also a significant difference between the length of career and the maximum racing grade reached during a dog's racing career (p <0.001) Dogs that had less racing success (reached a maximum race grade of C0 or C1), had shorter career length than dogs that reached higher racing grades.

Regarding the number of days dogs had between races: 12% of Australian (n = 84/675) and 8% of New Zealand dogs (n = 143/1,718) had predominantly high-intensity racing intervals with one to four days between races; 33% of Australian (n = 225/675) and 35% of New Zealand dogs (n = 143/1,718) raced on a medium-intensity racing interval with five to ten days between races; 5% of Australian (n = 32/675) and 10% of New Zealand (n = 179/1,718) dogs raced on a low-intensity racing interval with more than 10 days between races; and 49% of Australian (n = 333/675) and 45% of New Zealand (n = 778/1,718) dogs were not categorised due to having fewer than 50% of racing starts in each category. Dogs with a higher proportion of high frequency races had significantly more racing starts during their career compared with dogs that raced less frequently (p <0.001). Within the New Zealand dogs, there was a significant difference between the frequency of racing category and the career length, number of career racing starts, and finish age (p <0.001). New Zealand born dogs with a greater proportion of high-intensity racing intervals had more racing starts during their career. Dogs with predominantly high- or low- intensity racing intervals had shorter racing careers than greyhounds that raced on a medium-intensity racing interval or with no defined racing pattern. New Zealand dogs that raced predominantly on low-intensity racing intervals finished racing at a younger age than greyhounds racing predominantly more frequently or with no defined racing pattern. There was a significant difference between the number of racing starts for the racing frequency groups in Australian dogs, where dogs with a higher proportion of high-intensity racing intervals had more racing starts (p <0.001), however, there was no difference between racing frequency groups and career length nor finish age.

Summary measures for the age dogs finished their racing careers are presented in Table 2.2. There was a significant difference in finish age between New Zealand dogs (median: 36 months, IQR: 29-43 months) and Australian dogs (median: 39 months, IQR: 33-46 months). Dogs from Australia were significantly more likely to finish racing at a later age than New Zealand dogs (Log-rank p-value <0.0001) (Figure 2.2).

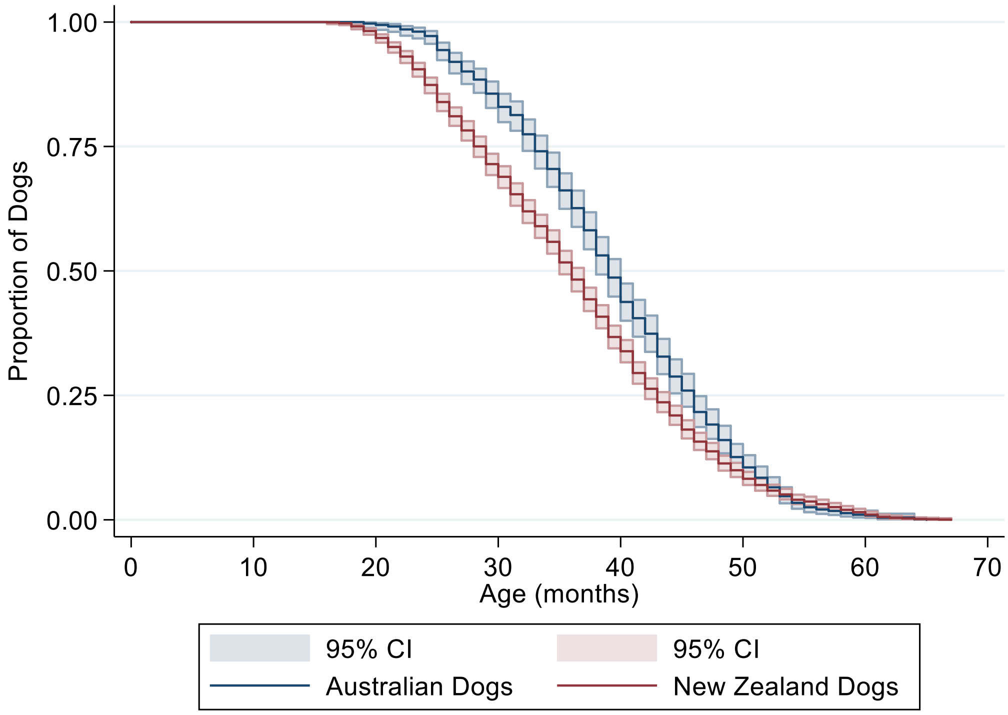


Figure 2.2 Kaplan-Meier 'survival' curve of the age of final racing start (months) stratified by country for a cohort of racing greyhounds in New Zealand. The coloured area around each line represents 95% confidence intervals.

However, there was no significant difference between the age of New Zealand and Australian born dogs at their last racing start when dogs that had achieved similar maximum racing class were compared (Table 2.3) (p>0.2 for all groups). A higher proportion of Australian born dogs reached class 5 (highest race grade) (40%) compared to New Zealand born dogs (17%).

Table 2.3 Summary information for the age finished racing (months) by the maximum race grade reached during the dog's career for New Zealand and Australian born dogs, for a cohort of greyhounds that raced in New Zealand during the 2013-2016 racing seasons.

Maximum race grade	**Australian dogs**			**New Zealand dogs**			**Total**		
	n	**Median age (months)**	**IQR**	**n**	**Median age (months)**	**IQR**	**n**	**Median age (months)**	**IQR**
C0	34	27	24-34	388	26	23-31	422	26	23-31
C1	110	32	27-37	434	33	28-38	544	33	28-38
C2	81	39	33-43	251	40	34-44	332	39	34-44
C3	109	39	33-47	197	41	36-48	306	40	35-48
C4	69	40	35-45	155	41	37-47	224	41	36-47
C5	272	43	38-48	293	43	37-48	565	43	37-48
Total	675	39	33-46	1,718	36	28-43	2,393	37	30-44

2.6 DISCUSSION

The objective of this study was to determine the pattern of racing and career duration for racing greyhounds in New Zealand. To the authors' knowledge, this is the first attempt to describe trends in greyhound racing careers. The regularity of the greyhound racing industry, in terms of the scheduling and location of race meetings provide the opportunity for dogs to race on a weekly basis. The study population consisted of all the dogs that raced during four seasons and encapsulates information about the racing careers of these dogs. The number, frequency, type and distribution of races remains consistent across all racing seasons, indicating that this sample could be considered representative of the current racing population in New Zealand.

While information around the number of dogs that were born but never had a racing start was not available from the data examined in this study, previous reports from New Zealand have estimated that 20-28% of dogs born were never registered for racing (Hansen, 2017). In the present study, of the dogs registered for racing, 9% failed to have a racing start in New Zealand. This figure is similar to the relatively low percentage loss of horses reported in the other two racing codes, with a 9% loss of Standardbred horses between registration for racing in New Zealand previously reported (Tanner et al., 2011, 2013). The moderately low number of dogs that did not race after registration suggests that there was genuine intention by owners and trainers to race their registered dogs.

The results from this study suggest that frequency of racing is driven by the regularity of race meetings at local racetracks. The pattern of racing is determined by the rigid structure of the racing calendar and industry scheduling of race meetings as suggested by the limited variation in the number of days between racing starts, number of races and number of race meetings. Within each region, there was limited variation in the patterns of racing, suggesting that trainers regularly travel to their local racetracks. Aside from the scheduling of race meetings, the greyhound racing industry is also constrained by the biology of the dog, The consistency of the racing system is a reflection of the balance between greyhound physiology, the size of the greyhound population available to race and the racing opportunities. Exploring the relationship between patterns of racing and career duration identified dogs that typically raced with high-intensity racing intervals and an equal sized cohort that predominantly raced with low-intensity racing intervals. Dogs that primarily raced less than once a week had shorter career lengths and fewer racing starts during their career compared with dogs that raced more frequently. Although there are differences between inter-race intervals amongst individual dogs, the reason for and the impact of these differences, in terms of health and injuries, remains unknown. Further research exploring the racing patterns of dogs, more specifically, investigating the reason why racing patterns differ between dogs is required. The small number of Australian dogs in the low-intensity inter-racing interval category is potentially due to the quality of dogs being imported from Australia, as well as the older median age they commence racing. To maximise the potential return for these Australian dogs, they would be required to race frequently. Although this present study identified that there are differences between the inter-racing interval for individual dogs, more research is required to determine the reason dogs fall into each of these categories.

The frequency of racing (median seven days between racing starts) is unique to the greyhound code, compared with the other racing codes where Thoroughbreds in New Zealand start in flat races a median of five times and jump races a median of three times each calendar year, and Standardbred pacers in New Zealand run a median of seven times every calendar year while Standardbred trotters race a median of eight times (Bolwell et al., 2014a, 2014b). Concerns surrounding the frequency of racing in greyhounds falls back to whether the dogs are racing too frequently and whether this predisposes them to racing injuries. Previous reports have demonstrated a high incidence of injuries (10-44%) involve central tarsal bone fractures in racing greyhounds (Boudrieau et al., 1984; Tomlin et al., 2000; Thompson et al., 2012), where the aetiology of the injury is due to accumulation of micro damage to distal limb bones through the application of cyclic stresses from training and racing (Muir et al., 1999; Tomlin et al., 2000; Holmes et al., 2014). The balance between bone fatigue, micro damage and the healing through adaptive remodeling is affected by the frequency of racing, as well as the amount of cyclic loading that is sustained during training and racing (Thompson et al., 2012). High accumulation of distance performed at racing speeds is seen to predispose Thoroughbred horses to musculoskeletal injuries as, in part, a result of skeletal and soft-tissue damage from repeated loads of high-speed or high-intensity exercise (Perkins et al., 2005). No similar studies for racing greyhounds have been undertaken and thus, there is a need to explore the impact that racing every seven days may have on the health and welfare of racing greyhounds.

Stevenson and colleagues (2009) found an increase in the number of racing starts by greyhounds, over a period of two months was associated with decreased injury risk (Stevenson et al., 2009). While this implies physical fitness is a protective measure, cumulative exposure of the greyhound's musculoskeletal system to the stresses involved with racing and training, despite having not been well documented, are considered to increase the risk of cyclic overload (Johnson et al., 2001; Stevenson et al., 2009; Beer, 2014). In the current study, the high-intensity racing interval dogs have more racing starts and shorter careers compared with the low-intensity racing dogs. This enables high-intensity racing dogs to have more racing starts over a shorter racing career. The reasons for shorter racing careers and fewer racing starts throughout a career appear multifactorial. Reasons may include dog-related factors where dogs with poor performance ability qualify for fewer starts than those that succeed earlier on in their racing careers, or may be due to injuries that shorten the career length (Beer, 2014). Since 2014, Greyhound Racing New Zealand have made a constructive effort to increase the opportunities to race in order to help extend the racing career length (Greyhound Racing New Zealand, 2014). The number of racing starts by New Zealand greyhounds appears to be much greater than the data reported from Victoria, Australia. While Beer (2014) did not specifically look at the whole career of racing greyhounds in Victoria, her work demonstrated that across a 6-year period, the median number of race starts for an individual dog was 10 (IQR: 4-25 starts). This current study reports a much higher number of racing starts with a median of 35 starts (IQR: 16-59).

The distribution of race age for Australian dogs suggests that these dogs are imported at different stages of their racing career. It is possible that the older median race age and first start age in Australian dogs compared with New Zealand bred dogs reported here are due to the imported dogs having previous racing starts in Australia, before commencing their racing career in New Zealand. This, in part, may explain the lower number of Australian dogs that trialled (n = 404) compared to raced (n = 675). Australian dogs that enter New Zealand with a previous suspension from racing are required to complete a satisfactory qualifying trial, whereas those that have been racing successfully in Australia before entering New Zealand are able to begin racing in the equivalent race grade they were competing in Australia. Australian dogs that have raced before entering the racing scene in New Zealand are imported at a later age and thus automatically have a shorter career duration and are older when they finish racing. Furthermore, the present study reported a greater number of Australian dogs than bitches. This, in part, could be due to the quality females being kept in Australia for breeding (Täubert et al., 2007; Beer, 2014). as opposed to potential stud dogs needing to be of exceptional quality to remain in Australia for breeding given that stud dogs mate with multiple bitches. In addition, the age Australian dogs cease racing is older than New Zealand dogs. This could, in part, be due to the effort and expense associated with importing a racing greyhound. In the current study, proportionally more imported dogs reached the higher racing grades during their career, which demonstrates that quality dogs are being selected for import into the New Zealand racing scene.

Dockerty (2017) and Helton (2009) report mean peak race performance is reached at ages of 2 years to 2.4 years (24 to 29 months) respectively. While race age has an influence on peak race performance, experience also plays a role in performance and this develops over time (Helton, 2009). Peak performance in racing greyhounds, in terms of race speed, occurs around 30-40 months of age (Täubert et al., 2007). The age distribution of racing greyhounds in New Zealand is similar to those reported for greyhounds racing in Ireland, where 50% of racing starts are by dogs of two years and under (Täubert et al., 2007). While speed information was not available for analysis in the current study, Dockerty (2017) found that racing age is correlated with speed; where speed improves until greyhounds are approximately 25 months of age, and then falls at a steady rate. In the present study, career duration was limited by the age of the dog. Dogs of similar ability, based on the maximum race grade reached during their career, finished racing at a similar age regardless of the age the dog began racing, the country the dog was from, or the total number of racing starts. Increasing age, past the point of peak athletic performance, has been clearly linked to a decline in maximal strength and power, which in humans, is due to a multifactorial array of endocrine changes, nervous system changes and muscle atrophy amongst other factors (Komi, 2008). There are limited statistics on the retirement age of canine athletes, however, this age has been crudely reported as five to six years for racing greyhounds (Hercock, 2010) and six years for dogs in other sporting disciplines in an Australian report (Branson et al., 2009).

The age at which dogs finish racing reflects a decline in peak athletic performance. Although there were differences between Australian and New Zealand dogs, greyhounds with similar racing ability, in terms of reaching the same maximum race grade, finished racing at the same age. Physiological responses to racing every seven days, as well as quantification of training practices that occur between race days in order to determine if the pattern of training and racing, has a profound effect on career longevity of racing greyhounds.

2.7 CONCLUSIONS

The racing careers of greyhounds racing in New Zealand has been studied using a dataset containing details on all greyhound racing starts over four consecutive racing seasons (2013-2016). Data contained 175,322 eligible racing starts by 4,807 individual dogs in 22,277 races. The number of racing tracks (n = 7), the number of race meetings, number of races, number of racing starts, and number of individual greyhounds racing showed no significant differences across the racing seasons. Furthermore, the pattern of racing and number of races remained consistent across the years, with more racing starts during winter compared to spring, summer and autumn. The majority of races (89%) had a full field of eight dogs, and races with seven or more runners accounted for 98% of all races. The age of the greyhounds racing ranged from 14 months through to 67 months with a median racing age of 31 months for New Zealand born dogs and 34 months for Australian born dogs. Dogs began their racing career at age 14 months and 47% of races were run as two-year-olds (24 to 36 months). Maiden races were primarily run by dogs 14- to 25-months old (64%), while the higher race classes (3, 4 and 5) were mostly run by dogs over 26 months of age.

This study has found that the median number of days between race starts was seven (IQR: 4-10). The pattern and frequency of racing is likely driven by the industry scheduling of race meetings. Dogs that primarily raced less than once a week had shorter career lengths and fewer racing starts during their career compared with dogs that raced more frequently. Differences between the inter-racing intervals for individual dogs are identified, but more research is required to determine the reason dogs fall into each of these categories. Furthermore, high-intensity racing interval dogs have shorter careers with more racing starts when compared with the low-intensity racing dogs. This enables high-intensity racing dogs to have more racing starts over a shorter racing career.

From the data I could not determine the impact that racing every seven days may be having on the health and welfare of racing greyhounds. But in their 2009 study Stevenson and colleagues found a decreased injury risk with an increase in the number of racing starts by greyhounds over a two-month period. It could be that physical fitness protects the greyhound's musculoskeletal system to the stresses involved with racing and training, but it is likely that cumulative exposure to cyclic overload increase the risk of injury long-term. I believe there is a need to explore the impact that racing every seven days may have on the health and welfare of racing greyhounds and that will be the focus of future work.

The present study has found that dogs of similar ability finished racing at a similar age regardless of the age the dog began racing, the country it was from, or the total number of racing starts it had. The age at which dogs finish racing reflects a decline in peak athletic performance. Although there were differences between Australian and New Zealand dogs, greyhounds with similar racing ability, in terms of reaching the same maximum race grade, finish racing at the same age.

REFERENCES

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2014a). Descriptive statistics and the pattern of horse racing in New Zealand. 1. Thoroughbred racing. *Animal Production Science*, *56*(1), 77-81.

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2014b). Descriptive statistics and the pattern of horse racing in New Zealand. 2. Harness racing. *Animal Production Science*, *56*(1), 82-86.

Boston, R. C., & Nunamaker, D. M. (2000). Gait and speed as exercise components of risk factors associated with onset of fatigue injury of the third metacarpal bone in 2-year-old Thoroughbred racehorses. *American Journal of Veterinary Research*, *61*(6), 602-608.

Boudrieau, R., Dee, J., & Dee, L. (1984). Central tarsal bone fractures in the racing Greyhound: a review of 114 cases. *Journal of the American Veterinary Medical Association*, *184*(12), 1486-1491.

Branson, N. J., Cobb, M. L., & McGreevy, P. D. (2009). Australian Working Dog Survey Report. *Australian Government Department of Agriculture Fisheries and Forestries*, Canberra, Australia.

Costelloe, A. (2019). *Greyhound racing deaths, injuries on Tasmanian tracks rise despite industry efforts*. ABC News. Retrieved April 24, 2019 from https://www.abc.net.au/news/2019-03-30/greyhound-deaths-injuries-rise-in-tasmania/10945234

Dohoo, I. R., Martin, W., & Stryhn, H. E. (2009). *Veterinary Epidemiologic Research* (2nd ed.). VER Inc. Charlottetown, Canada.

Greyhound Racing New Zealand. (2014). *Greyhound Racing New Zealand Annual Report* Greyhound Racing New Zealand. https://www.grnz.co.nz/Files/Documents/Final%20-%202014%20AGM%20Annual%20Report.pdf

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association.

https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf

Hansen, R. (2017). *Report to New Zealand Racing Board on welfare issues affecting greyhound racing in New Zealand*. New Zealand Racing Board.

Helton, W. S. (2009). Exceptional running skill in dogs requires extensive experience. *The Journal of General Psychology*, *136*(3), 323-336.

Hercock, C. A. (2010). *Specialisation for fast locomotion: performance, cost and risk* [Doctoral dissertation, University of Liverpool]. University of Liverpool Repository. https://livrepository.liverpool.ac.uk/id/eprint/3453.

Holmes, J., Mirams, M., Mackie, E., & Whitton, R. (2014). Thoroughbred horses in race training have lower levels of subchondral bone remodelling in highly loaded regions of the distal metacarpus compared to horses resting from training. *The Veterinary Journal*, *202*(3), 443-447.

Iddon, J., Lockyer, R., & Frean, S. (2014). The effect of season and track condition on injury rate in racing greyhounds. *Journal of Small Animal Practice, 55*(8), 399-404.

IER. (2018). *Size and scope of the New Zealand racing industry*.New Zealand Racing Board. https://www.rita.org.nz/sites/default/files/documents/NZ%20Racing%20Size%20and%20Scope%202018%20Full%20Report.pdf

Johnson, K. A., Skinner, G. A., & Muir, P. (2001). Site-specific adaptive remodeling of Greyhound metacarpal cortical bone subjected to asymmetrical cyclic loading. *American Journal of Veterinary Research*, *62*(5), 787-793.

Kaplan, E. L., & Meier, P. (1958). Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association*, *53*(282), 457-481.

Komi, P. (2008). *Strength and Power in Sport* (Vol. 3). John Wiley & Sons, Hoboken, New Jersey, United States of America.

Markwell, K., Firth, T., Hing, N. (2017). Blood on the race track: An analysis of ethical concerns regarding animal-based gambling. *Annals of Leisure Research, 20*(5), 594-609.

Muir, P., Johnson, K., & Ruaux-Mason, C. (1999). In vivo matrix microdamage in a naturally occurring canine fatigue fracture. *Bone*, *25*(5), 571-576.

Perkins, N., Reid, S., & Morris, R. (2005). Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 171-183.

Sicard, G., Short, K., & Manley, P. (1999). A survey of injuries at five greyhound racing tracks. *Journal of Small Animal Practice*, *40*(9), 428-432.

Sobczynska, 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.

Stevenson, M., Stafford, K., & Cave, N. (2009). *Risk factors for injury in New Zealand racing greyhounds: A report prepared for the New Zealand Racing Greyhound Association.* Massey University.

Tan, L. (2018). *NZ greyhound racing industry 'killing a dog a day for gambling profits'*. New Zealand Herald. Retrieved April 24, 2019 from https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12175451

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), 36.

Tanner, J., Rogers, C., & Firth, E. (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.

Tanner, J., Rogers, C., & Firth, E. (2011). The relationship of training milestones with racing success in a population of Standardbred horses in New Zealand. *New Zealand Veterinary Journal*, *59*(6), 323-327.

Tanner, J. C. (2011). *The association of 2-year-old training milestones with racing performance in standardbred and thoroughbred horses in New Zealand* [Master’s thesis, Massey University]. Massey Research Online. http://hdl.handle.net/10179/3942.

Täubert, H., Agena, D., & Simianer, H. (2007). Genetic analysis of racing performance in Irish greyhounds. *Journal of Animal Breeding and Genetics*, *124*(3), 117-123.

Thompson, D., Cave, N., Bridges, J., Reuvers, K., Owen, M., & Firth, E. (2012). Bone volume and regional density of the central tarsal bone detected using computed tomography in a cross-sectional study of adult racing greyhounds. *New Zealand Veterinary Journal, 60*(5), 278-284.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International*, *67*(3), 260-266.

Velie, B., Knight, P., Thomson, P., Wade, C., & Hamilton, N. (2013a). The association of age at first start with career length in the Australian Thoroughbred racehorse population. *Equine Veterinary Journal*, *45*(4), 410-413.

Velie, B., Wade, C., & Hamilton, N. (2013b). Profiling the careers of Thoroughbred horses racing in Australia between 2000 and 2010. *Equine Veterinary Journal*, *45*(2), 182-186.

PRELUDE TO CHAPTER 3

Before the effects of racing frequency on racing injuries can be assessed, it is important to quantify training practices. There are currently no data describing the training of racing greyhounds in New Zealand. A few studies mention a training regime that was used during research; however, no detailed information regarding training practices from a sample of greyhound trainers have been recorded.

Chapter 3 provides baseline information on the current training practices of racing greyhounds. A cross-sectional survey was used to describe weekly exercise regimes and training practices for racing greyhounds in New Zealand.

A version of this chapter has been previously published in Animals.

Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., Cochrane, D. J., & Bolwell, C. F. (2020). Cross-Sectional survey of the training practices of racing greyhounds in New Zealand. *Animals*, 10(11), 2032.

Chapter 3 CROSS-SECTIONAL SURVEY OF THE TRAINING PRACTICES OF RACING GREYHOUNDS IN NEW ZEALAND

3.1 SIMPLE SUMMARY

There is a limited amount of scientific literature about the training of racing greyhounds. Previous reports have focused on racing injuries, racetrack designs, and genetic traits of racing greyhounds, with little attention to training practices. Training and racing workload have been suggested as important factors associated with racing greyhound welfare and success. In this study, training practices of racing greyhounds were described by New Zealand trainers using a pro forma survey. This study found that trainers considered similar factors, 1) the ability to reach time milestones and 2) the appearance of young dogs, which indicated when they were ready to begin formal race training and racing, to be important when training young greyhounds. Training programmes for race-fit greyhounds were structured around a weekly cycle of two gallop workouts or races a few days apart, separated by walking and free exercise. Training practices appear to be specific to the metabolic and physiologic adaptations required for the challenges associated with sprint racing. This description of training practices provides baseline information about the workload of racing greyhounds in New Zealand.

3.2 ABSTRACT

The aim of this study was to conduct a cross-sectional study of racing greyhound trainers in New Zealand in order to provide an overview of their training practices. A survey regarding training practices was posted to all registered greyhound training licence holders in New Zealand in August 2019. Data were collected from a convenience sample of 48 trainers (36%; n = 48/137) who completed the survey. Other than the differences in the number of greyhounds in race training, the training programmes described by public trainers and owner trainers were similar. Trainers reported that the primary reason for registering young dogs for racing and for qualifying for racing was the ability to meet time milestones. Young dogs had a median of six (interquartile range (IQR): 4–10) trials before they commenced their racing career. Trainers described training practices that aimed to prepare greyhounds for race-day. Regardless of whether the dogs raced once or twice a week, most training

programmes demonstrated high specificity where training involved two periods of load cycles through high-intensity workload. Trainers racing their greyhounds once a week simulated the workload of trainers racing their greyhounds twice a week by introducing one high-intensity (speed) workout during the week. Training programmes were structured to condition the dogs to the physiological and metabolic requirements of sprint racing. This study highlights the importance of the need for an improved understanding of training and competition load in order to enable future research in the field of racing greyhounds.

3.3 INTRODUCTION

Generations of selective breeding have accentuated the physical attributes that allow greyhounds to be elite sprint athletes (Kesl, 1993; Williams et al., 2008). Their instinctive drive to chase (Howell & Bennett, 2020) combined with their ability to gallop at high speeds for a short duration has resulted in the sport of greyhound racing. Greyhounds are capable of reaching speeds of approximately 18 metres per second (Hudson et al., 2012) and achieve anaerobic metabolism during a race (Pellegrino et al., 2018). The greyhound racing industry in New Zealand is highly regulated, where the pattern of racing and opportunities to race remain consistent throughout the year (Palmer et al., 2020). In New Zealand, greyhounds are raced, on average, every seven days, over distances between 295 metres and 779 metres (Palmer et al., 2020). It has been suggested that training and racing frequency contribute to unfavourable dog welfare outcomes during races (Thompson et al., 2012; Palmer et al., 2020). There is minimal information, however, describing how greyhounds are prepared before and between races to test this hypothesis.

Exercise accumulated during training and racing has been demonstrated to influence racing performance (Verheyen et al., 2009; Ely et al., 2010; Bolwell et al., 2013) and the risks of musculoskeletal injury (Estberg et al., 1995) in Thoroughbred racehorses. A conditioning programme is designed with the primary aim of stimulating the specific physiological adaptations required for performance (Bayly, 1985; Rogers et al., 2007). For optimising performance, training sessions need to be correctly designed with well-balanced rest periods (Rogers et al., 2007). An understanding of the interaction between training volume (training intensity and frequency) and recovery periods can help identify training practices that avoid adverse dog welfare outcomes and is required to enhance performance (Rogers et al., 2007; Webb et al., 2020) in racing greyhounds.

In New Zealand, the training and racing of greyhounds is regulated by the governing body for greyhound racing (Greyhound Racing New Zealand) and the Racing Integrity Unit. There are two types of trainer licences in New Zealand, an owner trainer licence and a public trainer licence. Owner trainers are trainers that own at least a share in the greyhound or greyhounds in their training kennel. Public trainers are trainers who race and train greyhounds for themselves as well as members of the public. Trainers must abide by the Greyhound Racing New Zealand Rules of Racing and Welfare Standards, which specify the duty of care required to meet the physical, health, environmental, behavioural and mental needs of greyhounds under the jurisdiction of Greyhound Racing New Zealand (Greyhound Racing New Zealand, 2017, 2018). Kesl (1993) recognised that the training programmes of racing greyhounds vary widely, in part due to the dog’s athletic ability but also due to the convenience of the trainers. Previous reports have detailed exercise protocols used in research studies (Kesl, 1993; Hill et al., 2001); however, no detailed training information has been recorded at either trainer or dog level. Cross-sectional surveys have been used as a preliminary step to describe training practices in other animal sports, including Thoroughbred horse racing (Bolwell et al., 2010), Standardbred horse racing (Legg et al., 2020) and endurance horse competitions (Bolwell et al., 2015; Webb et al., 2020). Given the sparse documentation in scientific literature regarding racing and training practices of greyhounds, describing such practices will help understand the workload of racing greyhounds and is important to enable future research in this topic. The aim of this study was to provide an overview of the training practices of racing greyhound trainers in New Zealand and to examine if there were differences in practices between trainers with a public training licence and an owner trainer licence.

3.4 MATERIALS AND METHODS

The study was designed as a cross-sectional survey with a target population of all licenced greyhound trainers in New Zealand. A self-administered postal survey (Appendix 1) was distributed to all greyhound trainers (n = 137) that held a training licence for the 2019/2020 racing season (August–July) with Greyhound Racing New Zealand. To increase the response rate, further convenience sampling occurred at four North Island racetracks, where trainers were approached on race day and asked if they were willing to participate. Trainers that were approached at race meetings were provided the opportunity to complete the survey during an in-person interview. Follow-up phone calls were made with some trainers when surveys were returned incomplete. The potential for social responsibility bias was recognised and efforts to reduce such bias included ensuring the survey responses remained confidential and self-administration of the surveys where possible.

The survey consisted of a combination of 21 open, closed, and multiple-choice questions (Appendix 1), which took participants approximately 15 minutes to complete. The survey was divided into three sections; the demographics of the trainer (age, gender, type of training licence, number of greyhounds in training), training of young dogs before racing (age young dogs are broken in, milestones), and the structure of a typical training programme for greyhounds during the racing season. The questions referred to the greyhounds that were in training at the time of the survey. The project was evaluated by peer review and judged to be low risk by the Massey University Human Ethics Committee (Ethics Notification Number: 4000021550).

The trainers' answers were recorded and returned on a pro forma recording sheet and later entered into a Microsoft Excel (Microsoft, Redmond, WA, USA) spreadsheet for data manipulation. The exposure variable of interest was the type of licence held by the trainer (referred to as licence type), which was categorised by industry standards as either a public trainer or an owner trainer. Using these definitions "public trainers" can commercially train greyhounds for other people, whereas "owner trainers" only train their own greyhounds. Responses for free text answers were categorised into groups using key themes (Hsieh & Shannon, 2005). Data on training practices were grouped into categorical variables for racing frequency, number of low-intensity training sessions (including walking, free exercise, trotting, and swimming) and number of high-intensity workouts (galloping, trialling, or racing). The term trial refers to a controlled gallop event held at a racetrack where dogs run individually or as a competitive event, providing an opportunity for dogs to practice on the track. A qualifying trial is run under race conditions to select greyhounds ready to begin racing or for inclusion in a selected race. Data were summarised with median and interquartile range (IQR), and categorical and binary data were summarised as counts and percentages. Associations between the exposure and outcome variables were assessed using Fisher's exact test or Pearson's χ^2 test. A Kruskal–Wallis test was used to determine differences in the number of greyhounds in training for training licence types. Variables showing association with the outcome with p-values <0.05 were identified as exposure variables with a tendency towards statistical significance. The denominator for each question may vary as some questions did not apply to all trainers.

Statistical analyses were conducted in Stata version 15 (College Station, StataCorp LP, TX, USA).

3.5 RESULTS

3.5.1 Respondent demographics

A total of 48 trainers (36%; n = 48/137) completed the survey, three surveys were returned with insufficient detail to include in the analysis, two surveys were returned to sender and 84 trainers did not respond. Of the 48 surveys included in the analysis, 37 responses were returned by post and 11 were conducted in person. Nine of the 37 posted surveys were followed up with a phone call to complete the survey and/or clarify unclear responses. Most trainers who responded (71%; n = 34/48) were from the North Island, and responses were received from eight regions across New Zealand. In total, 67% (n = 32/48) of the respondents were male and more than half were aged between 51 and 70 years old (54%; n = 26/48) (Figure 3.1). The study population trained 663 actively racing greyhounds, which accounted for approximately 32% of the racing greyhound population in New Zealand in 2019.

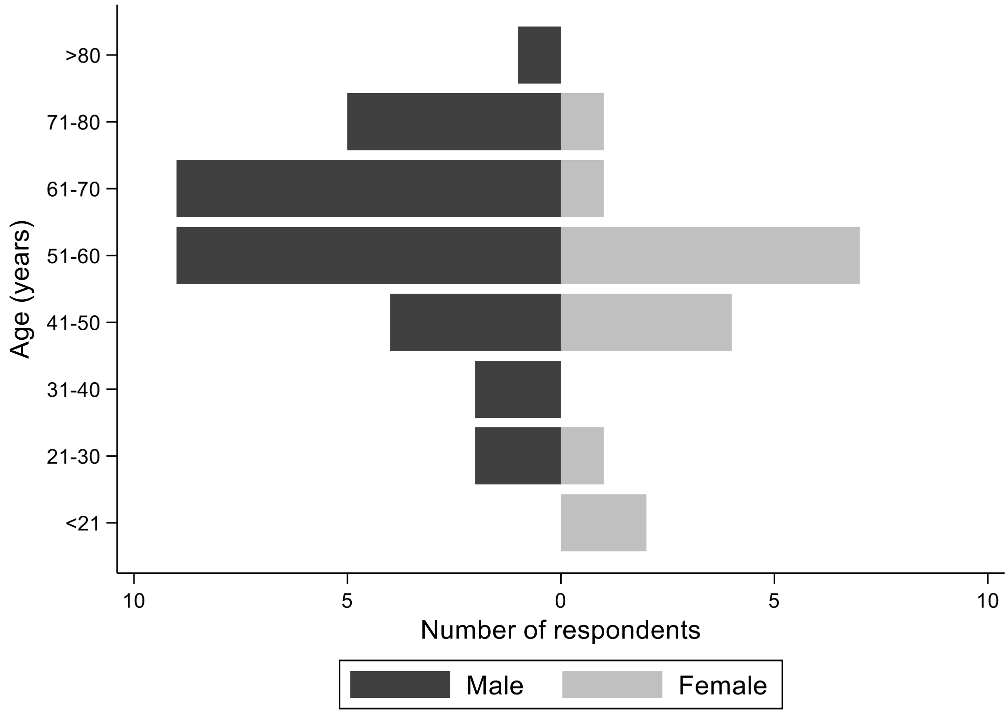


Figure 3.1 Population pyramid for age and gender of the 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand.

Respondents had a median of 20 years training experience (IQR: 10–30 years) and just under half of the trainers held a public training licence (46%; n = 22/48). Public trainers tended to have more greyhounds in training (median: 16 greyhounds; IQR: 10–28) than owner trainers (median: six greyhounds; IQR: 3–8) (p=0.0004).

3.5.2 Training facilities

Over half of the trainers (73%; n = 35/48) had a straight track (a long, narrow fenced off area where dogs could be hand slipped (released by a handler to chase a lure) or free galloped) to exercise their greyhounds, with two trainers having two separate straight tracks. The median distance of a straight track was 180 metres (IQR: 180–300 metres). Most straight tracks (89%; n = 34/37) were flat, with only four (11%) on a hill. Thirty-five trainers (73%) used an exercise paddock to train greyhounds, and paddocks had a median size of 0.4 hectares (IQR: 0.1–0.8 hectares). Four trainers (8%) reported having a circular training track. Most trainers (81%; n = 39/48) used a local racetrack for training, with a total of 10 different tracks around the country being used. Seven of these tracks were at locations of official greyhound race meetings and three were horse racing or training tracks that were used by greyhound trainers solely for the purpose of training. The different facilities used for training are shown in Table 3.1.

Table 3.1 Descriptive demographics, facilities used, and training methods of racing greyhounds as reported by 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand. Pearson's χ^2 or Fisher's exact test p-values are reported to demonstrate differences between the two groups of licenced trainers.

Variable	**Public Trainer** n (%)	**Owner Trainer** n (%)	**Total** n (%)	**p-value**
Number of trainers	22 (46)	26 (54)	48	
Location of trainers				0.227
Auckland	4 (8)	1 (2)	5 (10)	
Waikato	8 (17)	6 (12)	14 (29)	
Bay of Plenty	0	1 (2)	1 (2)	
Taranaki	0	3 (6)	3 (6)	
Manawatu-Whanganui	4 (8)	7 (15)	11 (23)	
Canterbury	5 (10)	6 (12)	11 (23)	
Otago	0	2 (4)	2 (4)	
Southland	1 (2)	0	1 (2)	
Facilities used for training				
Straight track				0.978
Yes	16 (33)	19 (40)	35 (73)	
No	6 (12)	7 (15)	13 (27)	
Exercise paddock				0.049
Yes	13 (27)	22 (46)	35 (73)	
No	9 (19)	4 (8)	13 (27)	
Training track				0.371
Yes	1 (2)	3 (6)	4 (8)	
No	21 (44)	23 (48)	44 (92)	
Treadmill				0.091
Yes	5 (10)	12 (25)	17 (35)	
No	17 (35)	14 (29)	31 (65)	
Beach				0.597
Yes	3 (6)	4 (8)	7 (15)	
No	19 (40)	22 (46)	41 (85)	
Local track				0.113
Yes	20 (42)	19 (40)	39 (81)	
No	2 (4)	7 (15)	9 (19)	
Train young dogs				0.357
Yes	18 (37)	19 (40)	37 (77)	
No	4 (8)	7 (15)	11 (23)	

Factors that influence trainers' decision to register young dogs for racing				0.347
Appearance	4 (8)	1 (2)	5 (10)	
Time milestones	8 (17)	9 (19)	17 (35)	
Weeks in training	1 (2)	1 (2)	2 (4)	
Owner decision	2 (4)	0	2 (4)	
All greyhounds are registered	3 (6)	6 (12)	9 (19)	
Age of the greyhound	0	1 (2)	1 (2)	
Factors that influence trainers' decision to qualify young dogs for racing				0.722
Appearance	3 (6)	4 (8)	7 (15)	
Time milestones	11 (23)	12 (25)	23 (48)	
Weeks in training	0	1 (2)	1 (2)	
Owner decision	1 (2)	0	1 (2)	
All greyhounds are qualified	1 (2)	1 (2)	2 (4)	
Training regime before first race				0.61
Standardised	4 (8)	4 (8)	8 (17)	
Similar (minor changes)	11 (23)	14 (29)	25 (52)	
Personalised	3 (6)	1 (2)	4 (8)	
Difference in training programme for greyhounds running different distances				0.626
Yes	12 (25)	13 (27)	25 (52)	
No	9 (19)	13 (27)	22 (46)	
Difference in training programme within 48 hours before a race				0.074
Yes	11 (23)	7 (15)	18 (37)	
No	10 (21)	19 (40)	29 (60)	
Training sessions recorded				0.446
Yes	7 (15)	12 (25)	19 (40)	
No	13 (27)	14 (29)	27 (56)	

3.5.3 Training practices

3.5.3.1 Preparing young dogs for racing

Seventy-seven percent (n = 37/48) of respondents trained young dogs in preparation for racing. Greyhounds began race training at a median age of 12 months (IQR: 11–14 months) and met the milestones of box training, speed work, hand slipping at the track and trialling at a median age of 13 months (IQR: 12–14 months), 14 months (IQR: 12–15 months), 14 months (IQR: 13–16), and 16 months (IQR: 14–16 months), respectively. Most trainers (76%; n = 28/37) reported giving young dogs a break during the breaking in process for a median of four weeks (IQR: 2–6) and this occurred either during the breaking in process (43%; n = 12), before their qualifying trial (39%; n = 11) or after their qualifying trial (18%; n = 5).

Thirty-three trainers (89%) reported trials being used during training for education purposes and 41% (n = 15) of trainers used them for improving greyhounds' fitness. Greyhounds typically completed six trials (IQR: 4–10) before they qualified for racing. The primary reasons for greyhounds being registered and qualified for racing are reported in Table 3.1. For many trainers, the primary milestone used to decide when a greyhound was ready to be registered or for a qualifying trial was the greyhound's ability to meet a minimum time (speed).

Twenty-five trainers (68%; n = 25/37) reported training greyhounds with standardised training programmes with minor adjustments for specific dogs, eight trainers (22%; n = 8/37) reported using standardised training programmes for all greyhounds and four trainers (11%; n = 4/37) reported following specifically tailored programmes for each greyhound (Table 3.1).

3.5.3.2 Training race-fit greyhounds

Over half of the trainers (67%; n = 32/48) reported that a typical greyhound will race once a week and 16 (33%; n = 16/48) trainers reported racing their greyhounds twice a week. Trainers exhibited a training micro-cycle structured around a weekly period (Figure 3.2).

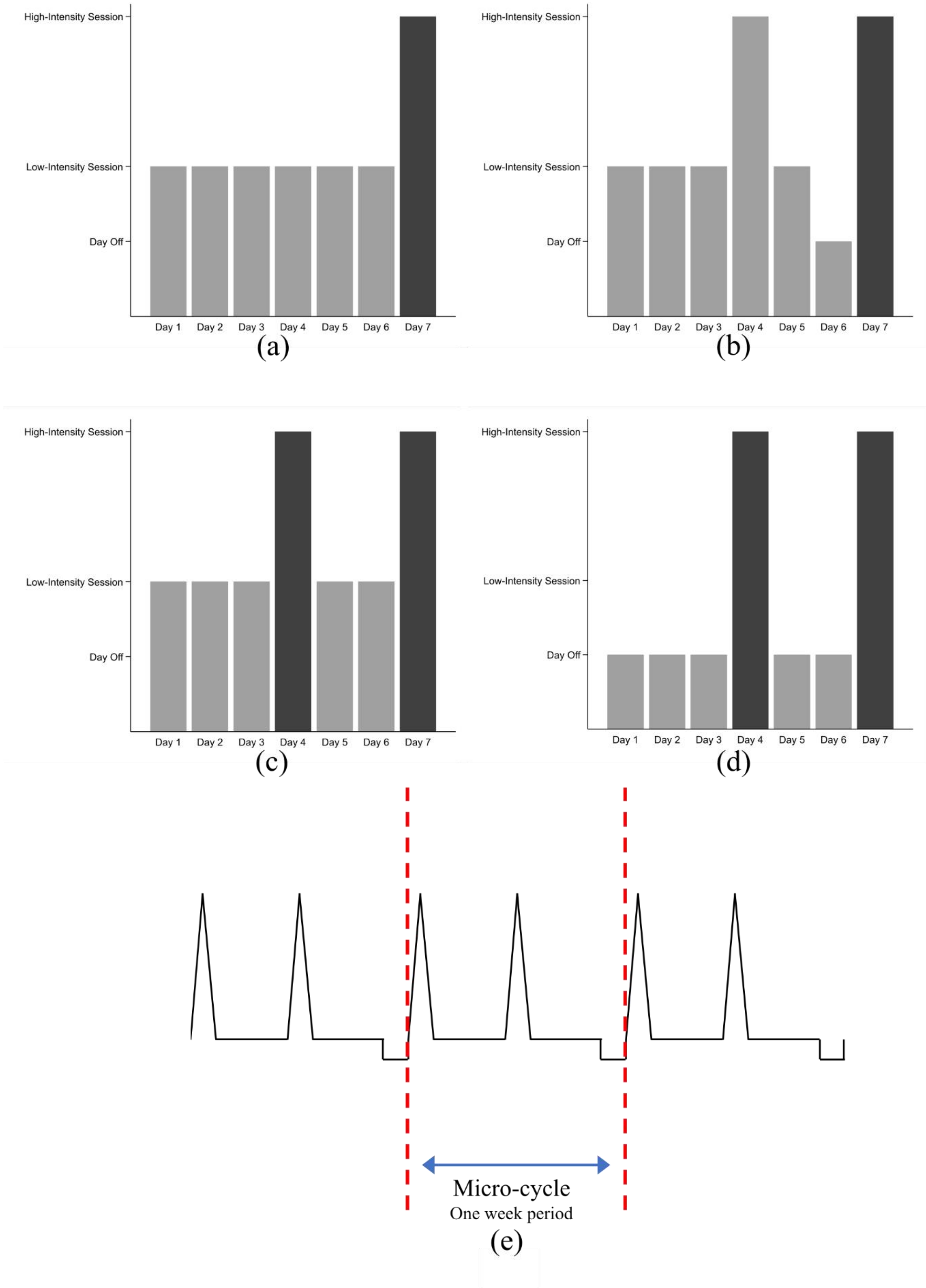


Figure 3.2. The four primary models of the training micro-cycle as described by

48 greyhound trainers across New Zealand. Racing days are highlighted by the dark grey bars and training days are shaded light grey; (**a**) low-intensity based training programme with one race (day seven) per week; (**b**) trainers give greyhounds one mid-week high-intensity training session; (**c**) low-intensity based training system with two race days per week; (**d**) training system where greyhounds race twice each week and do not participate in any workouts between race-days; (**e**) represents a typical training micro-cycle. The high-intensity training or racing load is indicated by the peaks, which are followed by a plateau of low-intensity work, which allows a period for rehabilitation and recovery before the next training load. Two of these cycles are typically followed by a rest period before the next load cycle. The racing schedule dictates the micro-cycle where greyhounds have two rest or low-intensity days to one high-intensity day.

Regardless of racing frequency, most training programmes involved two–three periods of high-intensity workload (73%; n = 35/48) per week. Most trainers racing their greyhounds once a week introduced a high-intensity training session during the week (63%; n = 20/32) (Figure 3.2). Twenty-two trainers (46%) did not gallop greyhounds between racing starts, 12 of these were trainers that typically raced their greyhounds once a week and 10 were trainers that raced greyhounds twice a week. Twenty-nine (60%) trainers reported that they did not make changes to the training schedule in the 48 hours leading up to a race.

There was no significant difference between trainers in the type of workout they gave their dogs before or after racing. Before and after a race, most training sessions involved a low-intensity workout (53%; n = 34/64 and 64%; n = 41/64, respectively), or the day off (44%; n = 28/64 and 31%; n = 20/64, respectively) (high-intensity workout before and after a race: 3%; n = 2/64 and 5%; n = 3/64, respectively). The pattern of training in the days surrounding high-intensity workouts was similar to the pattern of training around race days, where most trainers gave greyhounds a low-intensity workout (83%; n = 29/35) or the day off (14%; n = 5/35) the day before a gallop, and a low-intensity workout (80%; n = 28/35) or the day off (14%; n = 5/35) the day after a gallop.

Greyhounds performed low-intensity workouts for a median of four days per week (IQR: 3–5), which included walking, trotting, free exercise in a paddock or straight track and swimming/hydrotherapy. The median distance of low-intensity workouts was 3,000 metres (IQR: 1,800–4,000 m). Walking included road walking, with a median of 3,000 m (IQR: 1,800–4,000 m) covered per session, or treadmill, where the median was 15 minutes (IQR: 15–20 minutes) of time spent per session.

Trainers used high-intensity workouts, including galloping, trials, and racing, a median of two times per week (IQR: 1–3). The frequency and distance of training activities stratified by the number of race events trainers competed their dogs in per week are shown in Table 3.2.

Table 3.2 Frequency and distance of training activities (excluding racing) of racing greyhounds as reported by 48 trainers from a cross-sectional survey of the training practices of racing greyhounds in New Zealand.

Training activities	Racing once a week Median (IQR)	Racing twice a week Median (IQR)
Low-intensity training		
Median times per week	4 (3–5)	4 (2.25–5)
Median distance (metres) per training session	3,000 (1,875–4,000)	3,000 (1,800–3,250)
Total weekly distance (metres)	7,000 (2,750–16,000)	9,350 (6,675–13,750)
High-intensity training		
Median times per week	2 (1–2)	2 (2–3)
Median distance (metres) per training session [a]	457 (350–457)	457 (440–457)
Total weekly distance (metres)	727 (457–907)	989 (914–1,227.75)

[a] Distance including race distances. Where race distances were not given in the survey response, the median race distance for greyhound races in New Zealand from Palmer et al. (2020) was used (457 metres). Seventy-seven percent (n = 37/48) of trainers reduced the workout intensity or gave greyhounds the day off in the 48 hours before a race according to the weekly training schedules.

3.6 DISCUSSION

The aim of the study was to provide baseline data on the training practices of racing greyhound trainers in New Zealand. As far as the authors are aware, there are no previous studies detailing cross-sectional training information at either trainer or dog level, and the use of a survey provided the ability to collect data on training practices. Postal surveys of trainers can yield low response rates (Doherr et al., 1998), so after the initial postal distribution of surveys, a convenience sample of trainers was used for this study. Conducting surveys at race meetings provided an efficient method for promoting the survey, an opportunity to increase participation and the ability to aid participants with any queries to reduce non-response and errors. Therefore, the sample population was not entirely random and may have resulted in some selection bias. However, the geographical distribution of trainers in this study is consistent with previous reports for greyhound trainers across New Zealand (IER, 2018). The distribution of trainers in the study reflects the regions where racetracks are located and where racing regularly occurs. At the time the study was conducted, 64% (n = 88/137) of trainers in the target population were based in the North Island of New Zealand, 61% (n = 94/153 trainers including both individuals from training partnerships) of trainers were male and 39% (n = 54/137) held a public training licence. The gender of trainers included in this study and type of training licence held were consistent with the wider population. The median trainer age group of the target population was 41–50 years, which is lower than reported in this study; however, the proportion of trainers across the different age groups was similar. The distribution of the sample population reflected the demographics of the target population of registered trainers and can therefore be considered representative of the racing greyhound trainer population in New Zealand.

Training practices were mostly homogeneous with no significant differences between public trainers and owner trainers with regard to most of the facilities used for training and the general structure of the training programme. Such uniformity of training programmes has previously been described in racing Standardbred horses (Shearman & Hopkins, 1996) and Thoroughbred horses (Morrice-West et al., 2020).

There is potential that a social responsibility bias may have influenced the results of this study, particularly where anonymity was lost when surveys were completed in person or through phone communication. Such bias would mean that trainers answered questions according to how they perceived society (or the interviewer) to want them, rather than representing the facts (Crowne & Marlowe, 1960). Social responsibility bias cannot be ruled out as the reason why no differences were seen between training practices of public trainers and owner trainers. It is possible that trainers responded with information they considered as best practice for training, rather than detailing their actual regime which could have resulted in an under- or over-estimation of workload and the potential effects of bias could be in either direction. With such little literature on greyhound training practices, it is difficult to quantify the effects of social responsibility bias on the results of the study, however, the findings were consistent with insights gained during the preparation of the survey and were more uniform than expected. Due to limited availability of information about training practices of greyhounds before the survey was conducted, it was not possible to compare those that participated in the study with those that did not participate, preventing the bias created by the sampling method from being quantified. Specific factors may have contributed to non-response bias (Okafor, 2010). For example, trainers with larger number of greyhounds may have found the survey difficult to complete due to the generalisations required. Similarly, trainers with fewer greyhounds that had varying training regimes may have struggled to complete the survey. Such bias could result in an under- or over-representation of training workload. Furthermore, there was potential that differential recall bias (Neugebauer & Ng, 1990) influenced the results as respondents with varying training programmes would have been less likely to recall or report on all then nuances, compared to those with a set training regime. Fewer nuances would have been more memorable and easier to portray than varying training practices. This could have led to an underestimation in the type, frequency, and duration of training events, consequently the difference between trainers with significant variations in training regimes would not have been represented and training regimes could appear more consistent than is truly the case. Despite this, the results from this study make a significant contribution to knowledge of training practices because until now, workload of greyhounds has not been quantified and has relied on anecdotes and experience within the industry. In this study, although the overall structure of training was reported, numerous trainers noted that the programmes can vary between individual greyhounds as well as greyhounds racing different distances (i.e., sprinting greyhounds compared with long distance (staying) greyhounds). Despite overall training programmes being similar amongst the two groups of trainers, potential differences in the structure of training reported at individual dog level may occur.

Greyhounds have been selectively bred for speed and performance traits required for sprinting (Williams et al., 2008). Similar to reports from Thoroughbred racehorses (Rogers & Firth, 2004; Perkins et al., 2005; Rogers et al., 2020), greyhounds appear to require only a few gallop-load cycles to stimulate the appropriate musculoskeletal responses to race training. The training practices for young dogs described in this study reflect the requirements of performance bred canine athletes. The introduction of gallop work and trialling provides an initial loading phase, which conditions the greyhounds and provides the skill and specificity required for their racing career within a limited number of load cycles. This study found that during the conditioning phase of training, greyhounds typically commence training at 12 months of age and speed work at 14 months of age, which allows preparation for racing, which begins, according to industry standards, at 16 months of age (Rule 19.10) (Greyhound Racing New Zealand, 2017). Furthermore, greyhounds will partake in a median of six trials before they complete their qualifying trial and commence racing. In agreement with previous reports of athletic training (Borresen & Lambert, 2009), trainers noted that there was considerable variation between individual dogs, especially when training young dogs, in regard to the volume of training required to prepare the greyhound for racing.

Once the gallop and trial work commenced, greyhounds maintained a regular pattern where load cycles endured during racing, trialling or galloping work were balanced by rest days or days where low-intensity work occurs (Figure 3.2). A recent study reported that greyhounds race every seven days (Palmer et al., 2020), and thus once greyhounds reach a "maintenance" stage, trainers demonstrate a pattern where races and high-intensity workout sessions are used as a method to condition greyhounds, maintain fitness and provide load cycles. During high-intensity training sessions, greyhounds typically endure 70–91 load cycles (given that a greyhound's stride length is five metres and the median distance covered during high-intensity workouts is approximately 350–457 metres). greyhounds undertake two high-intensity workouts per week, either racing once and completing one gallop, or racing twice per week. Furthermore, despite most trainers reporting that changes were not made to the training programme in the days before a race, most trainers demonstrated tapering (reducing the intensity or no exercise) in the 48 hours before a race. This difference could be explained because the day-off or reduced workload before a race was not considered a change in the weekly micro-cycle; rather, tapering was a routine practice demonstrated when training greyhounds. The racing schedule dictates this micro-cycle of high-intensity and low-intensity training sessions (Figure 3.2).

Training programmes reported in this study appeared to be designed to improve anaerobic performance. Periods of high-intensity exercise provide opportunity for physiological adaptations required to enhance exercise performance. High-intensity workouts induce ATP (Adenosine Triphosphate) regeneration through the phosphagen and glycolytic systems (Nevill et al., 1989; Kesl, 1993; Baker et al., 2010), the activity of glycolytic regulatory enzymes, the accumulation of muscle and blood lactate (Rose & Bloomberg, 1989; Kesl, 1993), and changes in muscle pH (Kesl, 1993). The primary method of energy production for high-intensity performance is glycolytic metabolism (Bayati et al., 2011). Greyhound limbs contain a large proportion of fast-twitch type IIA muscle fibres (Guy & Snow, 1981; Rodriguez-Barbudo et al., 1984) and such muscle fibres have notable glycolytic capacity (Pellegrino et al., 2018). The reported training programmes were tailored to short duration bouts of anaerobic metabolism, which imitates the physiological requirements during racing, and we can therefore conclude that training programmes are specific to the metabolic system (Figure 3.3).

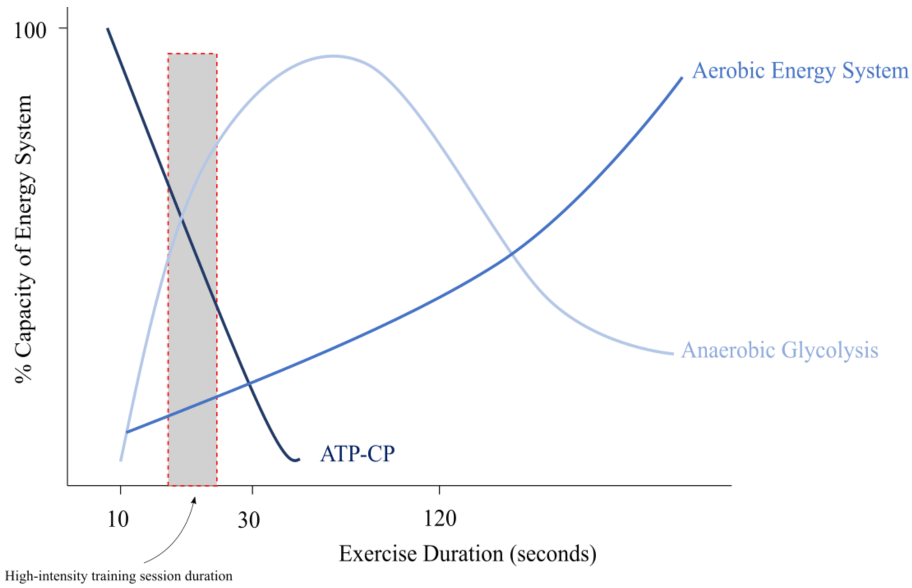


Figure 3.3 Training of the metabolic systems involved with energy production. During high-intensity workouts, the threshold at which anaerobic glycolysis becomes the predominant system for energy production is reached. Figure adapted from McArdle et al. (2010).

Furthermore, the training programmes appeared to be designed to prevent muscular injury, given that the risk of injury increases with increasing load cycles (Tomlin et al., 2000; Thompson et al., 2012) (Figure 3.4). Greyhounds are exposed to a high number of cumulative load cycles during training and racing. The magnitude and nature of these loads are influenced by the accumulation of exercise, training volume, rest periods and environmental factors (Rogers et al., 2007; Borresen & Lambert, 2009; Halson, 2014). The training programmes reported here were consistent with practices to reduce muscular injury. Previous studies have reported that most of the injuries recognised on race-day by veterinarians are categorised as general soreness affecting soft-tissue and could be considered a by-product of athletic pursuit (Beer, 2014; Palmer et al., 2021). The ratio of high-intensity workouts to low-intensity workouts suggests that the low-intensity sessions are used as an active recovery phase. Activity, commonly walking, is completed to allow a range of movements, to mitigate delayed onset of muscle soreness, to reduce the occurrence of bruising and to increase blood flow, which helps to flush out chemical waste (Morris, 2014).

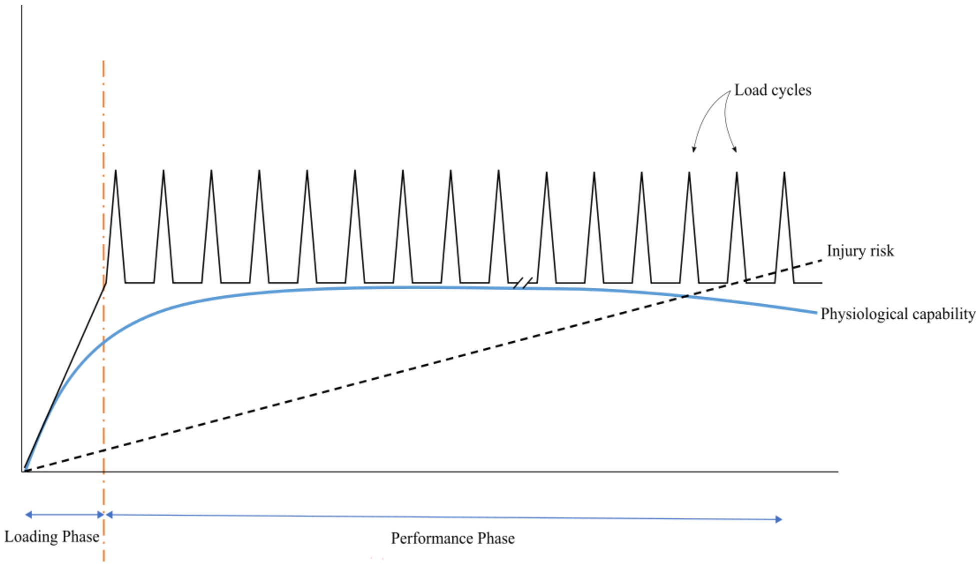


Figure 3.4 Loading and performance stages of greyhound training and racing. Young dogs are introduced to the stressors of racing during the load phase, and after 6–7 load cycles they commence racing in the performance phase. While the load cycles create a performance curve that is limited by the greyhound's physiological capabilities, with increasing number of load cycles and little time for recovery, the risk of injury increases.

It is likely that trainers use races to achieve specificity and stimulate appropriate physiological adaptations to maintain or improve performance. This study found that during the performance phase, where greyhounds are racing, they take part in repeated micro-cycles of high-intensity workouts including gallop sessions and racing. The structure of the micro-cycle was dictated by the opportunities to race. Races were used as a method to condition greyhounds and periods of low-intensity work that occurs between the load cycles are an active form of recovery where the trainers are managing their canine athletes. Previous work has demonstrated that, regardless of the age the greyhound began racing, greyhounds of a similar ability finished racing at a similar age (Palmer et al., 2020). Similar to all athletes, greyhounds have a period where they are at their physiological prime for the required speed work and the length of a racing career in greyhounds is limited by the age of the greyhound (Dockerty, 2017; Palmer et al., 2020). Regular racing during the window of time where greyhounds are at peak performance offers the greatest possible economic return for the trainer and/or owners of the greyhound. However, regular racing during this period leads to the accumulation of load cycles and thus an increasing risk of injury. The convergence at which the risk of injury increases due to accumulating load cycles is unknown for racing greyhounds and is an area where future work should be focused. Further prospective data capture of training regimes and physiological markers is required to examine the relationship between the quantity of load cycles, training volume and risk of injury.

3.7 CONCLUSIONS

This study provided baseline data on the training practices of racing greyhound trainers and highlighted factors unique to the greyhound racing industry in New Zealand. There were no significant differences between the training practices of trainers holding a public training licence compared with owner trainer licence holders. The training structure of racing greyhounds appears to be influenced by race-days, which help create a weekly micro-cycle. Regardless of whether a dog is racing once or twice a week, most training programmes demonstrated high specificity where training involved two high-intensity workload periods of load cycles. Periods of high-intensity exercise during training regimes are designed to improve anaerobic performance and provide opportunity for physiological adaptations required to enhance exercise performance. This study provides the necessary baseline data for future studies to explore.

REFERENCES

Baker, J. S., McCormick, M. C., & Robergs, R. A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, *2010*(1), 1-13.

Bayati, M., Farzad, B., Gharakhanlou, R., & Agha-Alinejad, H. (2011). A practical model of low-volume high-intensity interval training induces performance and metabolic adaptations that resemble 'all-out'sprint interval training. *Journal of Sports Science & Medicine*, *10*(3), 571-576.

Bayly, W. M. (1985). Training programs. *Veterinary Clinics of North America: Equine Practice*, *1*(3), 597-610.

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190.

Bolwell, C., Rogers, C., French, N., & Firth, E. (2013). The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Preventive Veterinary Medicine*, *108*(2-3), 188-198.

Bolwell, C., Russell, L., & Rogers, C. (2010). A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comparative Exercise Physiology*, *7*(1), 37-42.

Bolwell, C. F., Rogers, C. W., Rosanowski, S. M., Weston, J. F., Gee, E. K., & Gordon, S. J. (2015). Cross-sectional survey of the management and training practices of endurance horses in New Zealand: A pilot study. *Journal of Equine Veterinary Science*, *35*(10), 801-806.

Borresen, J., & Lambert, M. I. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine*, *39*(9), 779-795.

Crowne, D. P., & Marlowe, D. (1960). A new scale of social desirability independent of psychopathology. *Journal of Consulting Psychology*, *24*(4), 349-354.

Dockerty, R. J. (2017). *A Multifactorial Genetic Approach to Improving Welfare in the Racing Greyhound* [Doctoral dissertation, University of Liverpool]. The University of Liverpool Repository. https://livrepository.liverpool.ac.uk/id/eprint/3012340.

Doherr, M., Carpenter, T., Wilson, W. D., & Gardner, I. (1998). Application and evaluation of a mailed questionnaire for an epidemiologic study of Corynebacterium pseudotuberculosis infection in horses. *Preventive Veterinary Medicine*, *35*(4), 241-253.

Ely, E., Price, J., Smith, R., Wood, J., & Verheyen, K. (2010). The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine Veterinary Journal*, *42*, 624-629.

Estberg, L., Gardner, I. A., Stover, S. M., Johnson, B. J., Case, J. T., & Ardans, A. (1995). Cumulative racing-speed exercise distance cluster as a risk factor for fatal musculoskeletal injury in Thoroughbred racehorses in California. *Preventive Veterinary Medicine*, *24*(4), 253-263.

Greyhound Racing New Zealand. (2018). *Greyhound Health and Welfare Standards*. Greyhound Racing New Zealand. Retrieved 12 March 2019 from https://www.grnz.co.nz/Files/Rules%20and%20Policies/GRNZ%20Welfare%20Standards%20updated%201%20August%202021%20FINAL.pdf

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association. https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf.

Guy, P., & Snow, D. (1981). Skeletal muscle fibre composition in the dog and its relationship to athletic ability. *Research in Veterinary Science*, *31*(2), 244-248.

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44*(2), 139-147.

Hill, R. C., Fox, L. E., Lewis, D. D., Beale, K. M., Nachreiner, R. F., Scott, K. C., Sundstrom, D. A., Jones, G. L., & Butterwick, R. F. (2001). Effects of racing and training on serum thyroid hormone concentrations in racing Greyhounds. *American Journal of Veterinary Research*, *62*(12), 1969-1972.

Howell, T. J., & Bennett, P. C. (2020). Preventing predatory behaviour in greyhounds retired from the racing industry: Expert opinions collected using a survey and interviews. *Applied Animal Behaviour Science*, 226, 104988.

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277-1288.

Hudson, P. E., Corr, S. A., & Wilson, A. M. (2012). High speed galloping in the cheetah (Acinonyx jubatus) and the racing greyhound (Canis familiaris): spatio-temporal and kinetic characteristics. *Journal of Experimental Biology, 215*(14), 2425-2434.

IER. (2018). *Size and scope of the New Zealand racing industry*.New Zealand Racing Board. https://www.rita.org.nz/sites/default/files/documents/NZ%20Racing%20Size%20and%20Scope%202018%20Full%20Report.pdf

Kesl, L. D. (1993). *The effects of sprint training regimens and sodium bicarbonate loading on muscle glycolysis, lactate accumulation, acid-base balance, and performance in the racing greyhound* [Doctoral dissertation, Iowa State University]. Retrospective Theses and Dissertations. 10666. https://lib.dr.iastate.edu/rtd/10666/

Legg, K., Gee, E., Bolwell, C., Bridges, J., & Rogers, C. W. (2020). A Cross-Sectional Survey of the Training and Management of a Cohort of 2-Year-Old Standardbred Racehorses in New Zealand. *Journal of Equine Veterinary Science*, *87*, 102936.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology: nutrition, energy, and human performance* (7th Ed.). (pp. 226). Lippincott Williams & Wilkins. Philadelphia, United States of America.

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

Morris, D. (2014). *Training and racing the greyhound*. The Crowood Press. Ramsbury, Marlborough, United Kingdom.

Neugebauer, R., & Ng, S. (1990). Differential recall as a source of bias in epidemiologic research. *Journal of Clinical Epidemiology*, *43*(12), 1337-1341.

Nevill, M. E., Boobis, L. H., Brooks, S., & Williams, C. (1989). Effect of training on muscle metabolism during treadmill sprinting. *Journal of Applied Physiology*, *67*(6), 2376-2382.

Okafor, F. C. (2010). Addressing the problem of non-response and response Bias. *CBN Journal of Applied Statistics*, *1*(1), 91-97.

Palmer, A., Rogers, C., Stafford, K., Gal, A., & Bolwell, C. (2021). A retrospective descriptive analysis of race-day injuries of greyhounds in New Zealand. *Australian Veterinary Journal*, *99*(6), 255-262.

Palmer, A. L., Bolwell, C. F., Stafford, K. J., Gal, A., & Rogers, C. W. (2020). Patterns of racing and career duration of racing greyhounds in New Zealand. *Animals, 10*(5), 796.

Pellegrino, F. J., Risso, A., Vaquero, P. G., & Corrada, Y. A. (2018). Physiological parameter values in greyhounds before and after high-intensity exercise. *Open Veterinary Journal*, *8*(1), 64-67.

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

Rodriguez-Barbudo, M., Vaamonde, R., AguÈera, E., & Carpio, M. (1984). Histochemical and morphometric examination of the cranial tibial muscle of dogs with varying aptitudes (greyhound, German shepherd and fox terrier). *Zentralblatt fuer Veterinaermedizin, Reihe C (Germany, F.R.)* 13(4), 300-312.

Rogers, C., & Firth, E. (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.

Rogers, C., Rivero, J., Van Breda, E., Lindner, A., & van Oldruitenborgh-Oosterbaan, M. S. (2007). Describing workload and scientific information on conditioning horses. *Equine and Comparative Exercise Physiology*, *4*(1), 1-6.

Rogers, C. W., Bolwell, C. F., Gee, E. K., & Rosanowski, S. M. (2020). Equine musculoskeletal development and performance: impact of the production system and early training. *Animal Production Science*,60(18), 2069-2079. .

Rose, R., & Bloomberg, M. (1989). Responses to sprint exercise in the greyhound: effects on haematology, serum biochemistry and muscle metabolites. *Research in Veterinary Science*, *47*(2), 212-218.

Shearman, J., & Hopkins, W. (1996). Training of Standardbed maiden pacers. *Journal of Equine Veterinary Science*, *16*(3), 116-119.

Thompson, D., Cave, N., Bridges, J., Reuvers, K., Owen, M., & Firth, E. (2012). Bone volume and regional density of the central tarsal bone detected using computed tomography in a cross-sectional study of adult racing greyhounds. *New Zealand Veterinary Journal*, *60*(5), 278-284.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International*, *67*(3), 260-266.

Verheyen, K. L., Price, J. S., & Wood, J. L. (2009). Exercise during training is associated with racing performance in Thoroughbreds. *The Veterinary Journal*, *181*(1), 43-47.

Webb, H. J., Weston, J. F., Norman, E. J., Cogger, N., Bolwell, C. F., & Rogers, C. W. (2020). A descriptive study of training methods for Fédération Equestre Internationale (FEI) endurance horses in New Zealand. *Journal of Equine Veterinary Science*, 92, 103155.

Williams, S., Wilson, A., Rhodes, L., Andrews, J., & Payne, R. (2008). Functional anatomy and muscle moment arms of the pelvic limb of an elite sprinting athlete: the racing greyhound (Canis familiaris). *Journal of Anatomy*, *213*(4), 361-372.

PRELUDE TO CHAPTER 4

There is currently a paucity of recent information on the occurrence of musculoskeletal injuries that occur during racing in greyhounds in New Zealand.

The research presented in Chapter 4 provides baseline data on the incidence of injuries of racing greyhounds in New Zealand. This chapter presents a retrospective study that was used to determine the primary types of injuries sustained in racing greyhounds as well as the severity, cause and distribution of injuries.

Chapter 4 is based on a publication in the Australian Veterinary Journal.

Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., & Bolwell, C. F. (2021). A retrospective descriptive analysis of race-day injuries of greyhounds in New Zealand. *Australian Veterinary Journal*, 99(6), 255-262.

Chapter 4 A RETROSPECTIVE DESCRIPTIVE ANALYSIS OF RACE-DAY INJURIES OF GREYHOUNDS IN NEW ZEALAND

4.1 ABSTRACT

4.1.1 Objectives

To describe the distribution, and determine the incidence, of veterinary reported injuries experienced by greyhounds during racing in New Zealand.

4.1.2 Materials and methods

This retrospective cohort study utilised data obtained on all greyhound race starts and all racing injuries sustained in New Zealand between 10 September 2014 and 19 June 2019. Greyhound injuries were described by the number and percentage of the type, location, and presumed cause of injuries. The overall incidence of injuries per 1,000 racing starts was calculated and stratified incidence rates were calculated for race year, racetrack, race number, sex of the greyhound, country of origin of the greyhound, starting box number, race type, race class and race distance. Poisson regression was used to calculate incidence rate ratios (IRR) for the outcome of injury and race exposure variables.

4.1.3 Results

There were 213,630 race starts and 4,100 injuries. The incidence of injury was 19.2 (95% CI: 18.6-19.8) per 1,000 starts, whilst the number of fatalities at the track was 1.3 (95% CI: 1.1-1.4) per 1,000 race starts. Most injuries experienced by greyhounds on race-day were minor (soft-tissue). Most injuries affected the limbs of the greyhounds (83%, n=3,393/4,100). The rate of injuries was higher in Australian dogs compared with New Zealand dogs, the incidence rate of injury increased with advancing age group and the incidence rate varied amongst racetracks.

4.1.4 Conclusion

The injury rates were similar to those previously reported for racing greyhounds in New Zealand. This study highlighted the need for greater uniformity and conciseness around the classification of injuries to permit comparisons across jurisdictions.

4.2 INTRODUCTION

There has been increased public attention regarding the welfare of animals used in sport and production. Athletic pursuits of any description, including animal sports such as dog racing, are associated with injuries, the rate and magnitude of which can vary. Any injury to a dog is a welfare issue, but also at an industry level it represents lost opportunity and financial loss (Beer, 2014). Greyhounds are agile, high-speed athletes and they predominantly experience injuries to parts of the musculoskeletal system involved in locomotion and acceleration. This is, in part, due to the forces generated by ground-limb contact, especially while travelling around bends, which leads to increased predisposition to injuries (Hayati et al., 2017).

Over recent decades, multiple studies and reports (for example: Auer, 1999; Sicard et al., 1999; Stevenson et al., 2009; Beer, 2014) have focused on identifying and calculating the incidence rates and risk factors for injuries and fatalities in racing greyhounds. Globally, the incidence of musculoskeletal injuries reported on race day range from 5.5 injuries per 1,000 racing starts in the United States (Sicard et al., 1999), through to a high of 36.8 injuries per 1,000 racing starts in Australia (Beer, 2014). There is variation between racing jurisdictions as to how injuries are classified and reported, which makes comparisons difficult. In New Zealand, the incidence of injuries in racing greyhounds, at three tracks between 2003 and 2008, was previously reported as 19.6 injuries per 1,000 starts (Stevenson et al., 2009). However, improvements in the sensitivity, including level of detail, of the data recorded since this report was published, has necessitated a review of recent data and the establishment of an up-to-date baseline incident rate across all tracks.

As part of race-day procedures, on-track veterinarians detect and assess the severity of the injury while Stipendiary Stewards record details of where on the track the injury is believed to occur and how the injury occurred, which they then enter into an online recording system. The database of racing injuries can be used to determine the incidence of injuries and fatalities, as well as providing descriptions of the injuries sustained. The reporting and analysis of injuries is essential to assess their causes and address what changes can be made to minimise them (Stevenson et al., 2009). In their study, Stevenson and colleagues (2009) recognised the need for improved sensitivity when reporting injuries. Subsequent to this report, Greyhound Racing New Zealand, the governing body for greyhound racing, altered the injury reporting process in order to capture more information on each injury to facilitate the monitoring of injury rates (M Stewart, personal communication).

There are no recent studies reporting the incidence of musculoskeletal injuries in New Zealand racing greyhounds. The objective of this study was to describe the type and incidence of race-day veterinary reported injuries experienced by racing greyhounds in New Zealand.

4.3 MATERIALS AND METHODS

4.3.1 Study design, population and data collection

A retrospective cohort study was conducted using data from all greyhound racing starts in New Zealand between 10th September 2014 and 19th June 2019. Race-day veterinary injury information, race start data and greyhound information data were retrieved from Microsoft Excel files supplied by Greyhound Racing New Zealand (GRNZ). The study population consisted of all greyhounds declared to race in at least one race during the study period.

As part of normal race-day procedures, every greyhound is checked by an on-track veterinarian before being securely kennelled prior to each dog's race. Any greyhounds deemed unfit to race are thoroughly examined and subsequently scratched from the race. Stipendiary Stewards monitor and review the recording of each race and any greyhounds considered to have sustained an injury are sent to the racetrack veterinarian for a clinical examination. Furthermore, the on-track veterinarian and/or trainers can request a greyhound be checked after it has raced (Rule 56.1) (Greyhound Racing New Zealand, 2017).

Injuries are documented by the veterinarian onto forms that are then entered into the GRNZ injury database by the Stipendiary Steward chairing the race meeting. Veterinary injury reports included the anatomical location of injury, the severity of the injury, the place on the track where the injury occurred, as well as the imposed stand-down period required for the greyhound to recover. Details of the anatomical location (numbered as per a supplied diagram) of the injury, as well as the penetrometer (device used to measure track firmness) reading for the track surface, were only broadly described in the data, which prevented a detailed analysis of these variables. Race level data included the race date, box number (randomly allocated position in the starting boxes), finishing position, trainer name, greyhound name, race grade (the grade of the race where class 0 (C0) are maiden races, class 1 (C1) are lower grade races and there is a sequential increase to the higher grade races until class 5 (C5)), meeting location (track) and race distance. Greyhound level information included whelp date (date born), date of trial, date of first start, sex of greyhound, microchip number and the greyhound's ear tattoo. The greyhound ear tattoo was used to create a new variable for the country in which the greyhound was whelped, being either New Zealand or Australia.

An injury was defined as any event that involved a greyhound requiring veterinary attention on race-day and for which an injury reported was generated in the GRNZ database. A greyhound could contribute to several starts and multiple injuries over the study period. Greyhounds that were withdrawn before entering the starting boxes (starting a race) were excluded. A fatality was defined as an injury that resulted in death from catastrophic injury or euthanasia of the greyhound on race-day.

4.3.2 Statistical analysis

Data were organised for analysis in Microsoft Access 2016 and Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) and the integrity of the data were checked using exploratory data analysis. Dates of race start and date whelped were used to create new variables including race age and number of days between racing starts. New variables were created for race year, season (spring: September-November, summer: December–February, autumn: March-May, winter: June-August), whether the greyhound was injured during the race and whether the greyhound was fatally injured or died during the race. The age at racing start variable was categorised into groups (based on quartiles: 14-26 months, 27-32 months, 33-39 months and 40-79 months). The type of injury, cause of injury and anatomical area of the greyhound the injury affected variables were re-categorised where descriptions with low numbers were grouped to form an 'other' category. Injury stand-down period was grouped according to the categories recognised by Greyhound Racing New Zealand where the number of days the greyhound is not allowed to race reflects the severity of the injury. Injuries were further categorised by severity using the method described by Beer (2014), where injuries were grouped into four categories by the number of days the greyhound received as a stand-down: 'Minor injuries' (1-7 day stand-down), 'Moderate injuries' (8-20 day stand-down), 'Serious injury' (>21 day stand-down or euthanasia), and 'Death'.

Normality of continuous data was assessed with the Shapiro-Wilk test. Continuous data that were non-normally distributed were summarised with medians and interquartile range (IQR). Injuries were summarised as counts and percentages by variables describing the type, cause, anatomical location and severity of injuries. The incidence of injuries, accompanied by the binomial exact 95% confidence interval (CI), were calculated and reported as events per 1,000 racing starts for all variables for the overall study period. Stratified incidence rates were calculated to determine the association between injuries and the explanatory variables of race year, racetrack, race number (the order of the race at a meeting), sex of the greyhound, country of origin of the greyhound, starting box number, race type, race class and race distance.

Poisson regression in a generalised linear model was used to estimate incidence rate ratios (IRR) with 95% confidence intervals at a univariable level for race exposure variables and the outcome of injury. An initial Poisson model was fitted to each dataset that contained only an intercept term and a random effect coding for greyhound identity, to assess for the presence of clustering at the level of dog, by determining whether a dog-level variance term was different to zero. In the model, the variance at the dog level was different from zero ($p \leq 0.5$), indicating clustering at the level of the dog. All model development was then completed by including a random effect coding for dog to account for clustering at dog level.

The association between each of the race exposure variables and the outcome was screened by including one variable at a time into the Poisson model and assessing the effect of the variable on the outcome. Variables included dog sex, country of origin of the greyhound, year, racetrack, race number (the order of the race at a meeting), starting box number, race type (distance), race grade and dog age (months). The level of statistical significance was set at $p<0.05$. Further multivariable analyses were not completed given that the focussed research question was to calculate the incidence of musculoskeletal injuries sustained by racing greyhounds.

Statistical analyses were conducted in Stata version 15 (College Station, StataCorp LP, TX, USA).

4.4 RESULTS

Over the four-year study period there were 213,630 race starts made by 5,428 individual greyhounds at 2,145 different race meetings. The population was comprised of 3,013 dogs (56%) and 2,415 bitches (44%); 3,978 (73%) were New Zealand whelped greyhounds and 1,450 (27%) were Australian whelped greyhounds. Over half of the racing starts were undertaken by male dogs (n = 124,929/213,630: 59%) and 75% (n = 160,691/213,630) of starts were by New Zealand greyhounds. During the study period, the median number of racing starts was 32 (IQR: 14-56) race starts per greyhound. The median age at any race start was 32 months (IQR: 26-39). Age information was not available for 109 greyhounds, which accounted for 858 racing starts.

A total of 4,100 injuries were reported, 271 (7%) of these resulted in either euthanasia (n = 268) or death on the track (n = 3). The overall incidence of injuries was 19.2 per 1,000 starts (95% CI: 18.6-19.8). The incidence of non-fatal injuries was 17.9 (95% CI: 17.4-18.5) per 1,000 starts and the incidence of fatalities was 1.3 (95% CI: 1.1-1.4) per 1,000 starts. Of the total number of racing starts, 1% (n = 2,562/213,360) were not completed, 711 of these were due to injuries and of these 116 (16%) resulted in the greyhound dying or being euthanased on race day. A total of 2,635 greyhounds were injured and the median number of injuries per greyhound was 2 (IQR:1-2).

Details of the number and incidence of injuries and fatalities stratified by the description of the type of injury are summarised in Table 4.1.

Table 4.1 Number and incidence of injuries experienced on race day by racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019.

Injury type	n injuries [a] (%)	n euthanased or died (%)	Incidence [a] per 1,000 starts (95% CI)	Incidence of dogs euthanased or died per 1,000 starts (95% CI)
General soreness[b]	1,441 (35)	1 (0.4)	6.7 (6.4-7.1)	0.005 (0.0001-0.03)
Muscle tear or sprain	1,355 (33)	10 (4)	6.3 (6.0-6.7)	0.04 (0.02-0.09)
Laceration	640 (16)	2 (1)	3.0 (2.8-3.2)	0.009 (0.001-0.03)
Fracture	479 (12)	254 (94)	2.2 (2.0-2.5)	1.2 (1.0-1.3)
Other [c]	185 (5)	4 (0.1)	0.9 (0.7-1.0)	0.02 (0.005-0.05)

[a] Including fatalities

[b] General soreness defined as a physical complaint where the type of injury could not be determined and in some cases could not be anatomically identified.

[c] Other injury types included split webbing (n = 138/4,100), cramp (n = 38/4,100) and haemorrhage (n = 9/4,100).

The reported causes of injuries sustained by greyhounds during a race are summarised in Table 4.2. The cause of 1,528 (37%) injuries, including 38 (14%) fatalities, was unknown (unclassified by Stipendiary Stewards). A large proportion (n = 1,319/1,528; 86%) of these 'unknown cause' injuries were soft-tissue injuries (general soreness: n = 439/1,528, 29%; muscle tear or sprain: n = 609/1,528, 40%; laceration: n = 271/1,528, 18%) and most 'unknown cause' fatalities were fractures (n = 32/38, 84%). A total of 3,775 (92%) injuries occurred during a race, 263 (6%) injuries occurred after a race, 31 (1%) injuries occurring before a race and 31 (1%) injuries occurred at the starting boxes. Of the unknown cause of injuries, 1,396 (91%) occurred during the race, 102 (7%) occurred after the greyhound passed the finish line and the remaining 30 (2%) occurred either before the race or at the starting boxes.

Table 4.2 Number and incidence of the different aetiologies of injuries experienced on race day by racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019.

Cause of injury	n injuries (%)[a]	n euthanased or died (%)	Incidence [a] per 1,000 starts (95% CI)	Incidence of dogs euthanased or died per 1,000 starts (95% CI)
Unknown[b]	1,528 (37)	38 (14)	7.2 (6.8-7.5)	0.2 (0.1-0.2)
Interference with other greyhound [c]	1,317 (32)	76 (28)	6.2 (5.8-6.5)	3.6 (2.8-4.5)
Checked and fell	474 (12)	54 (20)	2.2 (2.0-2.4)	0.3 (0.2-0.3)
Faltered[d]	387 (9)	84 (31)	1.8 (1.6-2.0)	0.4 (0.3-0.5)
Struck the rail	191 (5)	5 (2)	0.9 (0.8-1.0)	0.02 (0.007-0.05)
Fall	87 (2)	9 (3)	0.4 (0.3-0.5)	0.04 (0.02-0.08)
Unbalanced leaving boxes	58 (1)	1 (0.4)	0.3 (0.2-0.4)	0.005 (0.0001-0.03)
Ran into lure	51 (1)	11 (4)	0.2 (0.2-0.3)	0.05 (0.03-0.09)
Collapsed	7 (0.2)	2 (1)	0.5 (0.4-0.6)	0.009 (0.001-0.03)

[a] Including fatalities
[b] Cause of injury was unclassified by Stipendiary Steward
[c] Including interference (n = 1,034/4,100), dragged down (n = 111/4,100), clipped heels (n = 86/4,100), jostled (n = 86/4,100)
[d] Faltered is when a greyhound became unsteady with no interference from other greyhounds.

The number and anatomical location of injuries experienced in the study period are summarised in Table 4.3. Of the 4,100 injuries, 83% (n = 3,393) were to the limbs; 49% (n = 2,015) involved the hindlimb and 34% (n = 1,378) involved the forelimb. The incidence of hindlimb injuries and forelimb injuries were 9.4 and 6.5 per 1,000 starts, respectively.

Table 4.3 Number and incidence of the anatomical location on greyhound where race day injuries occurred in racing greyhounds in New Zealand recorded by on-track veterinarians and Stipendiary Stewards between September 2014 and June 2019.

Anatomical location on the greyhound	n injuries (%)[a]	n euthanased or died (%)	Incidence [a] per 1,000 starts (95% CI)	Incidence of dogs euthanased or died per 1,000 starts (95% CI)
Right hindlimb	1,021 (25)	133 (49)	4.8 (4.4-5.1)	0.6 (0.5-0.7)
Left hindlimb	837 (20)	41 (15)	3.9 (3.7-4.2)	0.2 (0.1-0.3)
Left forelimb	680 (17)	50 (19)	3.2 (2.9-3.4)	0.2 (0.2-0.3)
Right forelimb	601 (15)	34 (13)	2.8 (2.6-3.0)	0.2 (0.1-0.2)
Left-side	404 (10)	4 (1)	1.9 (1.7-2.1)	0.02 (0.005-0.05)
Right-side	280 (7)	1 (0.4)	1.3 (1.2-1.5)	0.005 (0.0001-0.03)
Other [b]	277 (7)	8 (3)	1.3 (1.1-1.5)	0.03 (0.02-0.07)

[a] Including fatalities

[b] Other including both hindlimbs (n injuries = 157/4,100), both forelimbs (n injuries = 97/4,100), tail (n injuries = 16/4,100), heart (n injuries = 5/4,100) and neck (n injuries = 2/4,100)

Of the 4,100 injuries reported, 659 (17%) occurred on a straight section of the track, 1,869 (49%) occurred on a bend, 140 (4%) occurred at the lure, the location where the remaining 1,161 injuries (30%) occurred was unknown. Thirty-six of the 271 fatalities (13%) occurred on a straight, 194 (72%) occurred on a bend, 32 (12%) occurred at the lure and 9 (3%) occurred at an unknown location on the track. The incidence of an injury occurring on a straight was 3.0 (95% CI: 2.9-3.3) per 1,000 racing starts and on a bend was 8.7 (95% CI: 8.4-9.2) per 1,000 racing starts.

The number and incidence of injuries stratified by stand-down period is reported in Table 4.4. The incidence of 'minor' injuries was 4.6 (95% CI: 4.4-4.9) injuries per 1,000 starts, the incidence of 'moderate' injuries was 7.7 (95% CI: 7.3-8.1) per 1,000 starts and the incidence of 'serious' injuries including greyhounds euthanased was 6.9 (95% CI: 6.5-7.2) injuries per 1,000 starts.

Table 4.4 Number and incidence of the categorised injury stand-down period (days) imposed in racing greyhounds in New Zealand between September 2014 and June 2019.

Injury stand-down period (days grouped)	n injuries (%)	Incidence per 1,000 starts (95% CI)
<7	293 (7)	1.4 (1.2-1.5)
7-9	706 (17)	3.3 (3.1-3.6)
10-13	990 (24)	4.6 (4.4-4.9)
14-20	648 (16)	3.0 (2.8-3.3)
21-27	459 (11)	2.1 (2.0-2.4)
>28	733 (18)	3.5 (3.2-3.7)
Euthanased / died	271 (7)	1.2 (1.1-1.4)

The results of the univariable Poisson regression analysis for injuries as well as the incidence of injuries stratified by sex, country of origin, race year, racetrack, race number at meeting, starting box number, race distance category, race grade, and age of the greyhound are summarised in Table 4.5 and Appendix 2. The random effect of dog accounted for a significant amount of variation (p=0.005) indicating clustering at the level of dog. After adjusting for clustering at the dog level, the incidence rate ratio varied significantly by age, where greyhounds in the older age categories sustained injuries at a higher rate than dogs aged 14-26 months (Table 4.5). Australian dogs had a higher injury rate than New Zealand dogs, and injuries were sustained at a higher rate at track A, track B, track F and track G compared with track C.

Table 4.5 Univariable Poisson regression for injuries experienced by racing greyhounds in New Zealand as reported by on-track veterinarians and Stipendiary Stewards (September 2014 and June 2019) (n = 213,630).

Variable	n starts	n injuries[a]	Injury incidence per 1,000 starts (95% CI)[a]	Incidence rate ratio (95%CI)	p-value	Wald p-value
Sex						0.84
Dog	124,929	2,374	19.0 (18.3-19.8)	Ref		
Bitch	88,701	1,726	19.5 (18.6-20.4)	1.01 (0.93-1.09)	0.84	
Country of origin						<0.001
New Zealand	160,691	2,917	18.2 (17.5-18.8)	Ref		
Australia	52,939	1,183	22.3 (21.1-23.6)	1.25 (1.15-1.35)	<0.001	
Race year						<0.001
2014[b]	38,125	774	20.3 (18.9-21.8)	1.12 (1.00-1.24)	0.05	
2015	44,076	981	22.3 (20.9-23.7)	1.27 (1.15-1.41)	<0.001	
2016	44,365	706	15.9 (14.8-17.1)	0.92 (0.83-1.02)	0.11	
2017	46,382	799	17.2 (16.1-18.4)	Ref		
2018[b]	40,682	840	20.6 (19.3-22.1)	1.22 (1.10-1.35)	<0.001	
Racetrack						<0.001
Track A	27,476	722	26.3 (24.4-28.2)	2.25 (2.01-2.51)	<0.001	
Track B	20,631	316	15.3 (13.7-17.1)	1.30 (1.14-1.50)	<0.001	
Track C	62,735	761	12.1 (11.3-13.0)	Ref		
Track D	13,064	130	10.0 (8.3-11.8)	0.82 (0.68-0.99)	0.04	
Track E	12,831	141	11.0 (9.3-12.9)	0.92 (0.76-1.10)	0.35	
Track F	25,023	716	28.6 (26.6-30.8)	2.42 (2.17-2.70)	<0.001	
Track G	51,870	1,314	25.3 (24.0-26.7)	2.12 (1.93-2.33)	<0.001	

Race number at meeting						<0.001
1	16,895	387	22.9 (20.7-25.3)	Ref		
2	16,884	350	20.7 (18.6-23.0)	0.91 (0.79-1.05)	0.2	
3	16,841	345	20.5 (18.4-22.7)	0.91 (0.79-1.06)	0.23	
4	16,823	333	19.8 (17.7-22.0)	0.89 (0.76-1.03)	0.12	
5	16,831	335	19.9 (17.8-22.1)	0.90 (0.77-1.04)	0.15	
6	16,840	347	20.6 (18.5-22.9)	0.93 (0.80-1.07)	0.31	
7	16,850	352	20.9 (18.8-23.2)	0.94 (0.81-1.09)	0.43	
8	16,836	287	17.0 (15.1-19.1)	0.77 (0.66-0.90)	<0.001	
9	16,711	295	17.7 (15.7-19.8)	0.80 (0.69-0.93)	<0.001	
10	16,720	302	18.1 (16.1-20.2)	0.82 (0.71-0.96)	0.01	
11	16,424	300	18.3 (16.3-20.4)	0.83 (0.71-0.97)	0.02	
12	16,027	269	16.8 (14.9-18.9)	0.77 (0.66-0.90)	<0.001	
13-23	12,948	198	15.3 (13.2-17.6)	0.66 (0.56-0.79)	<0.001	
Starting box number						0.01
1	26,786	489	18.3 (16.7-19.9)	Ref		
2	26,740	544	20.3 (18.7-22.1)	1.11 (0.98-1.25)	0.09	
3	26,675	552	20.7 (19.0-22.5)	1.13 (1.00-1.28)	0.05	
4	26,701	507	19.0 (17.4-20.7)	1.04 (0.92-1.18)	0.53	
5	26,620	513	19.3 (17.7-21.0)	1.05 (0.93-1.19)	0.42	
6	26,712	558	20.9 (19.2-22.7)	1.14 (1.01-1.29)	0.03	
7	26,714	474	17.7 (16.2-19.4)	0.97 (0.85-1.10)	0.6	
8	26,682	463	17.4 (15.8-19.0)	0.95 (0.84-1.08)	0.44	

Race type						0.06
Sprint	139,505	2,746	19.7 (19.0-20.4)	Ref		
Middle	70,087	1,291	18.4 (17.4-19.4)	0.93 (0.87-1.00)	0.06	
Distance	4,038	63	15.6 (12.0-19.9)	0.80 (0.61-1.03)	0.09	
Race grade						0.07
C0	29,792	556	18.7 (17.2-20.3)	0.92 (0.83-1.01)	0.09	
C1	75,464	1,470	19.5 (18.5-20.5)	Ref		
C2	37,638	758	20.1 (18.7-21.6)	1.08 (0.98-1.18)	0.11	
C3	25,358	496	19.6 (17.9-21.3)	1.06 (0.95-1.18)	0.27	
C4	23,599	432	18.3 (16.6-20.1)	0.99 (0.88-1.10)	0.8	
C5	13,700	254	18.5 (16.3-20.9)	0.98 (0.85-1.13)	0.81	
Other [d]	8,079	134	16.6 (13.9-19.6)	0.88 (0.73-1.05)	0.16	
Age at time of injury (months) [c]						<0.001
14-26	59,746	861	14.6 (13.7-15.6)	Ref		
27-32	52,241	961	18.7 (17.6-20.0)	1.28 (1.17-1.41)	<0.001	
33-39	49,697	1,000	20.5 (19.3-21.8)	1.43 (1.31-1.58)	<0.001	
40-79	51,088	1,266	25.4 (24.0-26.8)	1.89 (1.72-2.08)	<0.001	

[a] Injuries including fatalities
[b] Data were not available for full racing seasons
[c] Age not available for 109 greyhounds across 858 racing starts; age data n = 212,772
[d] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

4.5 DISCUSSION

The incidence of injury in New Zealand racing greyhounds differs from international figures. The incidence of musculoskeletal injuries range from 5.5 injuries per 1,000 starts reported in the United States of America (Sicard et al., 1999) to 36.8 injuries per 1,000 starts reported in Australia (Beer, 2014). However, the rate of injuries described in this study is the same as the figure reported from three racetracks in New Zealand between 2003 and 2008 (19.6 per 1,000 starts) (Stevenson et al., 2009). Changes made to enhance the GRNZ injury database in 2014, as well as improvements to race-day reporting protocol, have allowed for injuries to be recorded in greater detail, with added diligence and a more systematic method of recording (M Stewart, personal communication). Most of the injuries in this study were recognised as general soreness during veterinary examination, and this category was not associated with substantial fatality rates. Most of the injuries detected affected soft-tissue and could be considered a by-product of athletic pursuit. Detection of such injuries demonstrates a thoroughness and rigour of veterinary examination. Differences in the injury rate reported from international studies suggests that the New Zealand injury reporting and recording system is sensitive to minor injuries. Despite differences in injury rate, the fatality rate remains similar amongst the recent studies of injuries in racing greyhound (Stevenson et al., 2009; Beer, 2014). Injury rates show promise as a method of monitoring the industry for progress in animal health and welfare. The lack of a consistent and detailed definition of what constitutes an injury for inclusion in a study, as well as variation in racing environments and management of greyhounds, makes comparisons of data from different countries and between studies difficult (Beer, 2014).

The incidence of injuries and fatalities increased with the age of the greyhound and this has been consistently reported in the literature (Stevenson et al., 2009; Beer, 2014). Stevenson et al. (2009) found that yearly increases in age at race start increased the odds of an injury or fatality 1.33 (95% CI: 1.19-1.49) times. Likewise, Beer (2014) demonstrated that the odds of a serious tarsal injury increased after the age of 27 months, with all age categories having at least two times the risk of suffering this injury compared with the reference group (<21 months of age). The reason for this trend is probably multifactorial, however, some have speculated that it may result from the cumulative exposure to the stresses of racing and training in the musculoskeletal system (Stevenson et al., 2009; Beer, 2014). Damage accumulated due to cyclic compression fatigue loading sustained during training and racing periods, has been implicated in the pathogenesis of structural failure of the bone resulting in fractures in racing greyhounds (Tomlin et al., 2000). However, the number of fractures reflects the approximate number of bone related injuries, which account for a small proportion of the injuries reported. Many of the injuries experienced by racing greyhounds involved soft-tissue. Greyhounds start racing early in life and have a compact racing lifespan with few rest periods which might allow for recovery and help prevent injuries occurring (Perkins et al., 2005; Palmer et al., 2020). Failure to provide an appropriate recovery period after episodes of accumulated load cycles endured during training and racing, have potential to impair racing performance and predispose athletic animals to further musculoskeletal injuries (Perkins et al., 2005; Rogers et al., 2007).

The stand-down period imposed by the on-track veterinarian for reported injuries can be considered an indication of the severity of the injury the greyhound has received. The severity of veterinary reported injuries in racing greyhounds, as categorised by Beer (2014), provides scope for the comparison of injury data, however, the stand-down period assigned to an injured greyhound is dependent on the on-track veterinarian's opinion as to the appropriate period that the greyhound should not race. Despite having a rigorous programme of detecting injuries, many injuries are vague in that there is not a definitive aetiology and that clinical diagnosis is based on a summative and functional basis. Injury stand-down periods have been used to categorise the severity of an injury. The incidence of minor injuries (using the categorisation described by Beer (2014)) in the present study was lower than the 19.0 per 1,000 starts as reported by Beer (2014), but incidence of serious injuries (injuries incurring a stand-down period greater than 21 days or euthanasia) were similar (6.0 injuries per 1,000 starts). There are industry variables which determine the length of the stand-down period imposed by an injury. Although most of the injuries were considered insignificant, the stand-down period can be treated as a protective measure undertaken to ensure the greyhound recovers well. Despite the similar structure and levels of reporting between racing authorities in New Zealand and Australia, differences in track design, track surface, injury reporting systems and race-day procedures, may contribute to the variation in rates reported from Australia. Given this, there is a need for a streamlined approach to determine differences, or similarities, across different racing jurisdictions that contribute to the rate of racing injuries.

The results in this study show variation in injury rates between racetracks, whereas the incidence of fatalities remain much less variable. Within New Zealand, there are differences in track design and track surface, which have been previously reported as risk factors for injuries in racing greyhounds in international studies (Cook, 1998; Iddon et al., 2014; Eager et al., 2017). Disparity in injury rates at different racetracks may not only be due to the physical track but could also be due to the subjective nature of injury detection. Furthermore, the criteria that individual Stipendiary Stewards and trainers use to determine if a greyhound is required to be checked by the on-track veterinarian differ. Minor injuries may go undetected until the greyhound has ‘cooled down’ or had a period of rest. Racetracks in the North Island of New Zealand had a higher incident rate of injuries than the tracks in the South Island. Whether or not this was due to injury detection or the design of the racetracks is unclear and warrants further investigation.

The results from this study agree with previous reports that most injuries were sustained at the bends on the track (Bloomberg & Dugger, 1998; Auer, 1999; Sicard et al., 1999). Track design has been considered a contributing factor to the risk of injuries, where nearly half of all injuries were thought to have occurred on the bend (Eager et al., 2017). In New Zealand the Stipendiary Stewards watch the race replay and attempt to determine the location on the track that the injury occurred, often coinciding with interference or faltering. Greyhounds accelerate to their fastest race speed in the first five seconds of a race, and from then on, they decelerate at a rate of approximately $0.13 m/s^2$ (Hossain et al., 2019). The point at which they are travelling the fastest is coming into or on the first bend of the race (Sicard et al., 1999). This combined with congestion as greyhounds try to hold their position in the race field, can lead to injuries (Beer, 2014).

The nature of greyhound racing, anti-clockwise around an oval track at high speed, predisposes greyhounds to specific racing injuries. While racing in the anti-clockwise direction, the right hindlimb and the left forelimb both impact the ground at great force (Dockerty, 2017). Centrifugal forces increase load and there is an increase in ground reaction forces on the bends (Davies et al., 2019). The mechanism in which greyhounds power locomotion through the hindlimb and support weight through the forelimb, allows greyhounds to maintain foot contact timings around a bend and to withstand a substantial increase in limb forces (Usherwood & Wilson, 2005; Williams et al., 2009). The distribution of the anatomical location of injuries on the greyhound are reported to reflect the forces endured by each limb during the greyhound's double suspension rotary gallop (Dockerty, 2017). In contrast to previous reports of racing injuries in greyhounds (Hickman, 1975; Prole, 1976), the incidence of hindlimb injuries appeared at a similar rate, however, right hindlimb injuries were more likely to be catastrophic compared to left hindlimb injuries. Even during the rotary gallop in a straight line there is asymmetrical loading of the hindlimbs such that the leading hindlimb (right) sustains greater force. During the bend racing greyhounds maintain stride frequency (Usherwood & Wilson, 2005; Hudson et al., 2012) which further accentuates this asymmetry and loading on the leading hindlimb (right). Evidence for this asymmetrical loading is provided in the description of higher bone mineral density in the right tarsal bones compared to the left tarsal bones (Johnson et al., 2000). Accumulated cyclic loading on the right hindlimb causes tarsal bones to increase in size and sustain a greater amount of matrix microdamage than the contralateral bone (Muir et al., 1999; Johnson et al., 2000). These reports provide supporting evidence that the difference in severity of the contralateral hindlimb injuries could be associated with asymmetrical loading.

It is possible that differences in internationally reported incidence rates and distribution of injuries occur through missing details or misclassification of the data reported. The monitoring and recording of injuries in racing greyhounds in New Zealand relies on an injury reporting form where the veterinarian and Stipendiary Stewards can write as much, or as little, information as deemed necessary (Injury reporting form - Appendix 3). There needs to be a greater consistency of injury reporting both nationally and internationally if progress in identifying risk factors and reducing incident rates is to be made. Information needed to make direct comparisons between the anatomical location of injuries simply did not exist. Developing a system to measure the frequency of injuries with high accuracy and precision is essential for racing jurisdictions to provide reliable data for understanding injury patterns, informing injury reduction schemes, and providing insights for policy control settings. While desirable for the racing industry, one shortcoming would be the lack of specificity to differentiate between types of injuries which have different aetiologies and incidence rates. The consistency of injury reporting is equally important, however, prioritising accuracy and precision would provide more information for the industry and standardisation of recording would follow once a robust system is established. A standardised incident report form, such as the Australian Racing Incident Database online system utilised by both the galloping and harness racing codes in Australasia, needs to be implemented by GRNZ, which would provide greater accuracy and consistency of the reported injuries occurring on race-day. Quantifying and describing the common racing injuries that affect greyhounds during their racing career will allow for risk factors to be addressed and further analysis aimed at reducing their occurrence.

4.6 CONCLUSIONS

This study was conducted to provide baseline levels of veterinary reported injuries in racing greyhounds in New Zealand. These rates are similar to injury rates previously reported for racing greyhounds in New Zealand. The incidence of injury in New Zealand racing greyhounds was greater than that reported in the USA and less than that reported in Victoria, Australia. However, the lack of a consistent and detailed definition of what constitutes an injury makes these comparisons more difficult. Overall, the type, cause and location of injuries observed was consistent with international studies. This study identified that the common injuries experienced by greyhounds on race-day were minor. Overall, this study highlighted the need for greater uniformity required to determine when a greyhound needs to be seen by a veterinarian as well as the need for conciseness around the classification of injuries. Industry driven standardisation and improved accuracy of recorded data is required to monitor the occurrence of injuries over time, and to safeguard the welfare of racing greyhounds.

REFERENCES

Auer, D., E. (1999). *Prevalence and type of injuries to racing greyhounds in South East Queensland.* World Greyhound Racing Federation Conference 2000, Sydney.

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190.

Bloomberg, M., & Dugger, W. (1998). Greyhound racing injuries: racetrack injury survey. In: M. S. Bloomberg, J. F. Dee, and R.A. Taylor (Eds.), *Canine sports medicine and surgery* (pp. 412-415). W.B. Saunders Company, Philadelphia, United States of America.

Cook, A. (1998). Literature survey of racing greyhound injuries, performance and track conditions. *Journal of Turfgrass Science*, *74*, 108-113.

Davies, Z. T. S., Spence, A. J., & Wilson, A. M. (2019). Ground reaction forces of overground galloping in ridden Thoroughbred racehorses. *Journal of Experimental Biology*, *222*(16), jeb204107.

Dockerty, R. J. (2017). *A Multifactorial Genetic Approach to Improving Welfare in the Racing Greyhound* [Doctoral dissertation, University of Liverpool]. The University of Liverpool Repository. https://livrepository.liverpool.ac.uk/id/eprint/3012340.

Eager, D., Hayati, H., & Hossain, M. (2017). *Identifying optimal greyhound track design for greyhound safety and welfare. Phase I Report January 2016 to 31 December 2016*. University of Technology Sydney.

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association. https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf

Hayati, H., Eager, D., Stephenson, R., Brown, T., & Arnott, E. (2017b). The impact of track related parameters on catastrophic injury rate of racing greyhounds. In *9th Australasian Congress on Applied Mechanics* (pp 311-317). Sydney Engineers Australia.

Hickman, J. (1975). Greyhound injuries. *Journal of Small Animal Practice*, *16*(1-12), 455-460.

Hossain, M. I., Eager, D., & Walker, P. (2019). Simulation of racing greyhound kinematics. *Proceedings of the SIMULTECH 2019 - 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (pp 47 – 56), Prague, Czech Republic.

Hudson, P. E., Corr, S. A., & Wilson, A. M. (2012). High speed galloping in the cheetah (Acinonyx jubatus) and the racing greyhound (Canis familiaris): spatio-temporal and kinetic characteristics. *Journal of Experimental Biology, 215*(14), 2425-2434.

Iddon, J., Lockyer, R., & Frean, S. (2014). The effect of season and track condition on injury rate in racing greyhounds. *Journal of Small Animal Practice, 55*(8), 399-404.

Johnson, K., Muir, P., Nicoll, R., & Roush, J. (2000). Asymmetric adaptive modeling of central tarsal bones in racing greyhounds. *Bone, 27*(2), 257-263.

Muir, P., Johnson, K., & Ruaux-Mason, C. (1999). In vivo matrix microdamage in a naturally occurring canine fatigue fracture. *Bone*, *25*(5), 571-576.

Palmer, A. L., Bolwell, C. F., Stafford, K. J., Gal, A., & Rogers, C. W. (2020). Patterns of Racing and Career Duration of Racing Greyhounds in New Zealand. *Animals*, *10*(5), 796.

Perkins, N., Reid, S., & Morris, R. (2005). Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 171-183.

Prole, J. (1976). A survey of racing injuries in the greyhound. *Journal of Small Animal Practice*, *17*(4), 207-218.

Rogers, C., Rivero, J., Van Breda, E., Lindner, A., & van Oldruitenborgh-Oosterbaan, M. S. (2007). Describing workload and scientific information on conditioning horses. *Equine and Comparative Exercise Physiology*, *4*(1), 1-6.

Sicard, G., Short, K., & Manley, P. (1999). A survey of injuries at five greyhound racing tracks. *Journal of Small Animal Practice*, *40*(9), 428-432.

Stevenson, M., Stafford, K., & Cave, N. (2009). Risk factors for injury in New Zealand racing greyhounds. *A report prepared for the New Zealand Racing Greyhound Association.* Massey University.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International*, *67*(3), 260-266.

Usherwood, J. R., & Wilson, A. M. (2005). No force limit on greyhound sprint speed. *Nature*, *438*(7069), 753-754.

Williams, S., Usherwood, J., Jespers, K., Channon, A., & Wilson, A. (2009). Exploring the mechanical basis for acceleration: pelvic limb locomotor function during accelerations in racing greyhounds (Canis familiaris). *Journal of Experimental Biology*, *212*(4), 550-565.

PRELUDE TO CHAPTER 5

The information from the descriptive analysis of racing injuries (Chapter 4) was used to direct the analysis in Chapter 5, where risk factors for the three main injuries sustained during racing (soft-tissue injuries, lacerations, and fractures) were explored. Injury types were analysed separately as it was hypothesised that the pathophysiology of soft-tissue injuries, lacerations and fractures would differ.

Chapters 2 and 3 identified that greyhounds have a homogeneous pattern of racing and training. The effect that frequency of racing has on racing injuries in greyhounds is unknown. Chapter 5 explores whether racing frequency has an effect on racing injuries.

Chapter 5 is based on a publication in Frontiers of Veterinary Science.

Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., & Bolwell, C. F. (2021). Risk-factors for soft-tissue injuries, lacerations and fractures during racing in greyhounds in New Zealand. *Frontiers in Veterinary Science*, 8, 737146.

Chapter 5 RISK FACTORS FOR SOFT-TISSUE INJURIES, LACERATIONS, AND FRACTURES DURING RACING IN GREYHOUNDS IN NEW ZEALAND

5.1 ABSTRACT

Recognition of injuries in racing animals is essential to identify potential risk factors so actions can be taken to reduce or mitigate the cause of the injury to safeguard the animal. Racing greyhounds are subject to musculoskeletal injuries associated with athletic pursuit, in particular soft-tissue injuries, lacerations, and fractures. The objective of this study was therefore to determine risk factors for soft-tissue injuries, lacerations and fractures occurring during racing, using a cohort of greyhounds racing in New Zealand between 10th September 2014 and 31st July 2020. Dog-level, race-level and track-level risk factors for each outcome were assessed using mixed-effects multivariable logistic regression including trainer as a random effect. Throughout the study period there were 218,700 race starts by 4,914 greyhounds, with a total of 4,385 injuries. Of these, 3,067 (70%) were classed as soft-tissue injuries, 641 (15%) were reported as lacerations, and 458 (10%) were fractures. Greyhounds with a low racing frequency (racing more than seven days apart) had 1.33 (95% confidence interval (CI): 1.06–1.67) times the odds of fracture compared to those racing more frequently. Older greyhounds had a greater odds of fracture compared with younger greyhounds. Racing every seven days had a lower odds of soft-tissue injury compared with racing more than once a week. Dogs over 39 months had 1.53 (95% CI: 1.35–1.73) times the odds of sustaining a soft-tissue injury compared to the younger dogs. Greyhounds originating from Australia had a higher odds of fracture and laceration compared with New Zealand dogs. Better performing dogs (higher class) had a greater odds of fracture and laceration whilst maiden dogs had a higher odds of soft-tissue injury. Greyhounds starting from the outside box had a higher odds of fracture. However, there was considerable variation in the odds of soft-tissue injury at different racetracks. In conclusion, although the incidence of soft-tissue injuries was higher than other injury types, the repercussion of such injuries was less than those for fractures. The results from this study will help to inform intervention strategies aimed at reducing the rate of injuries in racing greyhounds, enhancing racing safety and greyhound welfare.

5.2 INTRODUCTION

Within New Zealand there is an increasing quantity of data published from which it is possible to describe the greyhound (*Canis familiaris*) racing population and the structure of racing. This baseline data provides the opportunity to identify areas requiring improvements in order to safeguard the welfare of racing greyhounds. The current industry structure provides greyhounds with a constant opportunity to race throughout the year (Palmer et al., 2020a). These greyhounds race a median of every seven days and begin their racing career at a median of 21 months of age (Palmer et al., 2020a). In New Zealand, greyhounds race in an eight-dog field, around a circular sand track, chasing and finishing on a mechanical artificial lure. Not only do the greyhounds show a periodicity to the pattern of racing (Palmer et al., 2020a), but a previous study has reported that regardless of the number of times a greyhound races in a week, they have two high-intensity workload sessions, either training or racing, each week (Palmer et al., 2020b). Workloads, including training and competition load, contribute to injuries through fitness or fatigue. The physiological adaptations associated with each of these, as well as exposure to extrinsic (external) risk factors and the injury mechanism, wherein the biomechanical stress of an event is greater than the tolerance of the athlete, results in an injury occurring (Rogers et al., 2007; Windt & Gabbett, 2017).

Many factors influence the risk of injuries in racing greyhounds and studies have reported dog- and race- related risk factors, such as weight (Davis, 1973; Beer, 2014), race age (Stevenson et al., 2009; Beer, 2014), sex (Stevenson et al., 2009), speed at which the dogs race, track design and surface (Cook, 1998; Sicard et al., 1999; Beer, 2014; Iddon et al., 2014; Mahdavi et al., 2018), race distance (Sicard et al., 1999), race speed (Stevenson et al., 2009; Beer, 2014), grade of race (Sicard et al., 1999) and environmental-factors such as weather (Sicard et al., 1999) and month of the year (Sicard et al., 1999). Across these studies there is disparity in the risk factors identified and the magnitude of the risk reported that may reflect the governance of greyhound racing of the country in which they were examined. Moreover, there are differences between racing jurisdictions in the type and frequency of racing injuries sustained by racing greyhounds (Beer, 2014; Iddon et al., 2014; Palmer et al., 2021). In Australasia, soft-tissue injuries, fractures and lacerations are the most common race-day injuries reported for racing greyhounds (Beer, 2014; Palmer et al., 2021). Despite this, studies have focused on risk factors for all injury types collectively. It is widely recognised that risk factors for different injury outcomes will vary, and thus there is a need to identify risk factors specific to New Zealand racing for each of the common injury outcomes.

With limited data on injuries in racing greyhounds and obvious differences between racing jurisdictions, there was a need for a New Zealand specific study. Accordingly, the objective of the present study was to investigate risk factors for injuries described as 'soft-tissue injuries', 'lacerations' or 'fractures' reported during racing for greyhounds in New Zealand. Identification of risk factors that influence racing injuries could facilitate the necessary improvements and development of strategies that may reduce the incidence of injuries in racing greyhounds.

5.3 MATERIALS AND METHODS

5.3.1 Study design, population, and data collection

A retrospective cohort study was used to collect information regarding all race starts and all injuries occurring during greyhound races in New Zealand between 10th September 2014 and 31st July 2020. The study utilized data supplied as Microsoft Excel files by Greyhound Racing New Zealand (GRNZ). Data included race-day veterinary injury information, race start data and greyhound information data. The study population consisted of all greyhounds declared to race in at least one race during the study period, excluding dogs that were scratched before a race or deemed unfit to race upon a pre-kennelling veterinary examination. GRNZ supplied race start information for all dogs that started after 1st January 2013 and injury data from 10th September 2014 through to the end of the 2019/2020 racing season (31st July 2020). To capture all information on racing injuries, a cohort was created which included greyhounds that had their first race start on or after the 10th September 2014.

As part of normal race-day procedures, GRNZ-approved on-track veterinarians clinically examined every greyhound due to race that day before it was secured in its pre-race kennel. Any greyhounds deemed unfit to race are not allowed to race.

Immediately after each race, Stipendiary Stewards monitor and review the recording of the race and any greyhounds considered to have sustained an injury during or after the race are sent to the on-track veterinarian for a clinical examination. Furthermore, the on-track veterinarian and/or trainer can request a greyhound be checked after it has raced (Rule 56.1) (Greyhound Racing New Zealand, 2017). Details of any injuries sustained are recorded on standardised forms (Appendix 3) and then entered into the GRNZ injury database by the Stipendiary Steward chairing the race meeting. The inclusion criteria for an injury in this study was defined as any event that involved a greyhound requiring veterinary attention on race-day and for which an injury report was generated in the GRNZ database. A greyhound could have multiple starts and several injuries over the study period. A fatality was defined as an injury that resulted in the death or euthanasia of the greyhound on race-day.

Injury data included the anatomical location of injury, the severity of the injury, the place on the track where the injury occurred, and the imposed stand-down period required for the greyhound to recover. Race level data included the race date, box number (randomly allocated position in the starting boxes), finishing position, trainer name, greyhound name, race grade (the grade of the race where class 0 (C0) are maiden races, class 1 (C1) are lower grade races and there is a successive increase to the higher grade races through to class 5 (C5)), meeting location (track) and race distance. Greyhound level information included whelp date (date born), date of qualifying trial, date of first start, sex of greyhound, country in which the greyhound was whelped, microchip number and the greyhound's ear tattoo. Details of the anatomical location (numbered as per a supplied diagram) of the injury, as well as the penetrometer (device used to measure track firmness) reading for the track surface, were only broadly described in the data, which prevented a detailed analysis of these variables.

In this study, injuries were categorised as soft-tissue injuries (general soreness, muscle tear, muscle sprain), lacerations, fractures, or other injuries (split webbing, cramp, haemorrhage, and swelling). The type of injury, cause of injury and anatomical area of the greyhound the injury affected were re-categorised where descriptions that were not as common in the population were combined to form an 'other' category for each variable.

5.3.2 Statistical methods

Data were organised for analysis in Microsoft Access 2016 and Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) and the integrity of the data were checked using exploratory data analysis. Race date and date whelped were used to create new variables including age at the time of the race (race age) and number of days between racing starts. New variables were created for race year, season (spring: September-November, summer: December–February, autumn: March-May, winter: June-August), whether the greyhound was injured during the race and whether the greyhound was fatally injured or died during the race. Injury stand-down period was grouped according to the categories recognised by Greyhound Racing New Zealand where the number of days the greyhound is not allowed to race reflects the severity of the injury. Injuries were separately categorised by severity using the method described by Beer (2014), where injuries were grouped into four categories by the number of days the greyhound received as a stand-down: 'Minor injuries' (1-7 day stand-down), 'Moderate injuries' (8-20 day stand-down), 'Serious injuries' (>21 day stand-down), and 'Catastrophic injuries' (death or euthanasia). The number of races in different time periods were considered, however, given that most dogs race a median of seven days (IQR:3-9), this was collinear with the time-varying variables (number of races in the previous 7-day period, 14-day period, 21-day period and 28-day period) and so the days since the previous race start, which best described the data, was measured instead. New datasets were created for each injury description (soft-tissue injury, laceration, and fracture) and each dataset contained a binary outcome variable coding for the specific injury description for that dataset.

Normality of continuous data was assessed with the Shapiro-Wilk test. Continuous data that were non-normally distributed were summarised with medians and interquartile range (IQR). Injuries were summarised as counts and percentages by variables describing the type, cause, anatomical location, and severity of injuries.

Mixed effects logistic regression modelling was used to determine explanatory variables that were associated with each of the three outcomes (soft-tissue injury, fracture and laceration). Collinearity between continuous variables was assessed by calculating pairwise Pearson's correlation coefficients, where if pairs of variables had moderate or high correlation (p>0.4), the variable that best described the data was assessed in the multivariable model. The age at race start and the career race start number were highly correlated, as were the time-varying variables and the number of days since the previous racing start. Age at race start was retained in the models with the outcomes of fracture and soft-tissue injury, while the career race start number was retained in the model with the outcome of laceration. The number of days since previous racing start variable was retained in all three models. Analyses were carried out to determine if there was a linear association between a continuous explanatory variable and the log odds of soft-tissue injury, fracture or laceration risk. The log odds probabilities of greyhounds sustaining a soft-tissue injury, fracture or laceration, were plotted against each of the continuous variables using a smoothed line (Dohoo et al., 2009). Visual assessment of the resulting scatterplots were examined for linearity. If non-linearity was identified, addition of a quadratic term to the final model or categorisation of the continuous variables was considered. The assumption of linearity was considered violated if the log likelihood ratio test p-value was <0.05, and the smoothed line of the log odds probabilities indicated a non-linear relationship. When the assumption of linearity was not met, the explanatory variable was entered into the model as a categorical variable based on quartiles or biologically plausible groupings (age of greyhound, career race start number, and days since previous racing start). The age at racing start variable was categorised into evenly sized groups: 14-25 months, 26-31 months, 32-38 months, and 39-77 months. Career race start number was categorised into groups based on quartiles and the days since previous racing start variable was grouped in accordance to industry relevance (Palmer et al., 2020a) (more than one race per week, racing once per week and racing less than once a week). An initial logistic regression model was fitted to each dataset that contained only an intercept term and a random-effect coding for trainer, to determine the presence of clustering at the trainer level, by determining whether a trainer-level variance term was different to zero. In all models, the variance at trainer level was different from zero (p <0.05) providing evidence for clustering at the level of trainer. To account for clustering at trainer-level, a random effect coding for trainer identity was included into each of the models.

Potential explanatory variables were screened using univariable mixed effects logistic regression, and variables were selected for inclusion in subsequent multivariable models if they had a calculated probability of $p<0.2$. A backwards stepwise model building process was then used to develop a multivariable model and selection of variables was based on the likelihood ratio test p-value and/or Akaike information criterion. Explanatory variables that were not statistically significant were removed from the model one at a time, beginning with the least significant and variables with a likelihood ratio p-value of $p<0.05$ were retained in the model. Likelihood ratio tests were used to determine the significance of variables in the model and confounding was assessed by examining the effect of addition of variables on parameter estimates (a change of ≥20%). Biologically plausible two-way interaction terms were then considered for inclusion in the multivariable model and none were significant at an alpha level of 0.05. Separate analyses were performed for each of the three injury outcomes (soft-tissue injury, laceration, and fracture). Residual intraclass correlation coefficients were estimated for clustering at trainer level, using a latent variable approach (Snijders & Bosker, 1999) by including trainer as a random effect in each final multivariable logistic regression model. The fitted probability of the outcome for each model was calculated based on the final mixed effects logistic regression multivariable model. Model diagnostic tests were conducted using summary measures of the goodness-of-fit of the final model including the estimation of the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer & Lemeshow, 2000) and the Receiver Operating Characteristic curve. Residual values were calculated to assess the fit of the model and residuals close to 0 reflected a well-fitting model.

Statistical analyses were conducted in Stata version 15 (College Station, StataCorp LP, TX, USA).

5.4 RESULTS

During the study period there were 218,700 race starts by 4,914 individual greyhounds. There were 4,385 injuries reported, of which 3,067 (70%) were classed as soft-tissue injuries, 641 (15%) were reported as lacerations, 458 (10%) were reported as fractures, and 219 (5%) were reported as ‘other’ injuries. The distribution of racing starts and injuries is shown in Table 5.1.

Table 5.1 The distribution (number and percentage) of racing starts and injuries that occurred during greyhound races in New Zealand from 10th September 2014 to 31st July 2020.

Variable	Category	n starts (%)	n injuries (%)	n fracture (%)	n laceration (%)	n soft-tissue injury (%)
Sex						
	Dog	126,560 (58)	2,531 (58)	286 (62)	393 (61)	1,719 (56)
	Bitch	92,140 (42)	1,854 (42)	172 (38)	248 (39)	1,348 (44)
Country of origin						
	New Zealand	166,923 (76)	3,181 (73)	307 (67)	439 (68)	2,287 (75)
	Australia	51,777 (24)	1,204 (27)	151 (33)	202 (32)	780 (25)
Race age (months)						
	14-25	59,548 (27)	897 (20)	85 (19)	139 (22)	632 (21)
	26-31	57,871 (26)	1,039 (24)	117 (26)	158 (25)	718 (23)
	32-38	50,746 (23)	1,088 (25)	127 (28)	146 (23)	760 (25)
	39-77	50,535 (23)	1,361 (31)	129 (28)	198 (31)	957 (31)
Career start number						
	1-13	58,051 (27)	1,129 (26)	117 (26)	171 (27)	781 (25)
	14-28	52,386 (24)	980 (22)	97 (21)	148 (23)	690 (23)
	29-51	53,884 (25)	1,080 (25)	136 (30)	142 (22)	752 (25)
	52-231	54,379 (25)	1,196 (27)	108 (24)	180 (28)	844 (28)
Days since previous race						
	<7	86,537 (40)	1,719 (39)	155 (34)	269 (42)	1,211 (39)
	7	68,940 (32)	1,271 (29)	145 (32)	190 (30)	873 (28)
	>7	63,223 (29)	1,395 (32)	158 (35)	182 (28)	983 (32)

Race type						
	Sprint	142,530 (65)	2,945 (67)	306 (67)	423 (66)	2,082 (68)
	Middle	72,026 (33)	1,358 (31)	141 (31)	200 (31)	936 (31)
	Distance	4,144 (2)	82 (2)	11 (2)	18 (3)	49 (2)
Race grade						
	Class 0	34,037 (16)	643 (15)	52 (11)	94 (15)	467 (15)
	Class 1	73,000 (33)	1,456 (33)	135 (29)	195 (30)	1,045 (34)
	Class 2	37,642 (17)	819 (19)	74 (16)	117 (18)	591 (19)
	Class 3	25,845 (12)	530 (12)	61 (13)	85 (13)	358 (12)
	Class 4	18,750 (9)	368 (8)	49 (11)	45 (7)	259 (8)
	Class 5	22,514 (10)	457 (10)	75 (16)	86 (13)	272 (9)
	Other [a]	6,912 (3)	112 (3)	12 (3)	19 (3)	75 (2)
Racetrack						
	Track A	66,352 (30)	818 (19)	145 (32)	176 (27)	441 (14)
	Track B	13,009 (6)	122 (3)	17 (4)	28 (4)	64 (2)
	Track C	27,213 (12)	686 (16)	79 (17)	118 (18)	466 (15)
	Track D	52,386 (24)	1508 (35)	113 (25)	165 (26)	1151 (38)
	Track E	20,641 (9)	347 (8)	37 (8)	58 (9)	229 (7)
	Track F	13,283 (6)	125 (3)	21 (5)	19 (3)	77 (3)
	Track G	25,816 (12)	779 (18)	46 (10)	77 (12)	639 (21)

Starting box						
	1	27,396 (13)	527 (12)	37 (8)	71 (11)	393 (13)
	2	27,408 (13)	572 (13)	56 (12)	75 (12)	413 (13)
	3	27,259 (12)	578 (13)	62 (14)	87 (14)	404 (13)
	4	27,381 (13)	580 (13)	56 (12)	87 (14)	401 (13)
	5	27,213 (12)	550 (13)	61 (13)	82 (13)	377 (12)
	6	27,324 (12)	576 (13)	58 (13)	98 (15)	385 (13)
	7	27,374 (13)	504 (11)	56 (12)	75 (12)	351 (11)
	8	27,345 (13)	498 (11)	72 (16)	66 (10)	343 (11)
Season						
	Winter	59,433 (27)	1,221 (28)	106 (23)	171 (27)	877 (29)
	Spring	51,719 (24)	1,040 (24)	108 (24)	168 (26)	727 (24)
	Summer	54,465 (25)	1,097 (25)	117 (26)	146 (23)	775 (25)
	Autumn	53,083 (24)	1,027 (23)	127 (28)	156 (24)	688 (22)
Race year						
	2019/2020	40,419 (18)	1,044 (24)	77 (17)	134 (21)	773 (25)
	2018/2019	46,344 (21)	1,011 (23)	105 (23)	129 (20)	746 (24)
	2017/2018	46,137 (21)	793 (18)	87 (19)	124 (19)	540 (18)
	2016/2017	41,769 (19)	652 (15)	87 (19)	105 (16)	423 (14)
	2015/2016	32,419 (15)	683 (16)	73 (16)	109 (17)	464 (15)
	2014/2015	11,612 (5)	202 (5)	29 (6)	40 (6)	121 (4)

[a] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

Table 5.2 Description of the type of injury by the severity of the injury for injuries occurring during greyhound races in New Zealand from 10th September 2014 to 31st July 2020 (n = 4,385).

	Soft-tissue injury		**Laceration**		**Fracture**		**Other [a]**		**Total injuries**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Minor injuries [b]	242	8	76	12	3	1	28	13	349	8
Moderate injuries [c]	1,861	61	494	77	17	4	140	64	2512	57
Serious injuries [d]	962	31	69	11	211	46	47	21	1289	29
Death / euthanased	2	0.1	2	0.3	227	50	4	2	235	5
Total	3,067		641		458		219		4385	

[a] Other included split webbing (n=147/4,385), cramp (n=49/4,385), haemorrhaged (n=8/4,385) and swelling (n=8/4,385).

[b] Minor injuries includes injuries with a stand-down period of less than 7 days.

[c] Moderate injuries includes injuries with a stand-down period of 7-20 days.

[d] Serious injuries includes injuries with a stand-down period of 21 or more days.

Of the 4,914 individual dogs, 2,602 (53%) sustained at least one racing injury. Injury descriptions classified by the severity of the injury in terms of stand-down days are presented in Table 5.2. The overall incidence of injury was 20.05 per 1,000 starts (95% CI: 19.47–20.65) and 14.02 (95% CI: 13.54–14.53), 2.93 (95% CI: 2.71–3.17) and 2.09 (95% CI: 1.91–2.29) per 1,000 starts for soft-tissue injuries, lacerations and fractures respectively. There were 235 catastrophic injuries, and the overall incidence of catastrophic injuries was 1.07 per 1,000 starts (95% CI: 0.94-1.22). Approximately half the fracture cases (n = 227/458; 50%) were associated with a fatal outcome, two (0.31%) lacerations and two (0.07%) of the soft-tissue injuries were associated with a fatal outcome.

Male dogs comprised slightly more of the race starts throughout the study period (n = 126,560/218,700; 58%) and New Zealand born dogs accounted for 166,923 (76%) of the race starts. The median race age for all starts was 31 months of age (IQR: 25–38 months) and during the study period dogs had a median of 28 racing starts (IQR: 13–51 starts). Of the fractures (n = 458), 286 (62%) occurred in male dogs and 307 (67%) were in New Zealand born dogs. The median race age at time of fracture was 33 months (IQR: 27–40 months) and the median race start number when the fracture occurred was 30.5 (IQR: 13–51). Of the lacerations (n = 641), 393 (61%) were in male dogs and 439 (68%) occurred in New Zealand born dogs. The median age for a reported laceration was 33 months (IQR: 26–40 months) and the median number of race starts for dogs that sustained a laceration was 29 (IQR: 13–54). Reflecting the underlying racing population, more soft-tissue injuries were reported for male dogs (n = 1,719/3,067; 56%) and for dogs of New Zealand origin (n = 2,287/3,067; 75%). The median race age for soft-tissue injuries was 33 months (IQR: 27–41 months) and the median race start number when a soft-tissue injury occurred was 30 (IQR: 13–55).

The univariable models for the outcomes of fracture, lacerations and soft-tissue injury are presented in Table 5.3 and full univariable results are provided in Appendices 4-6.

Table 5.3 Univariable logistic regression results of risk factors for fractures, lacerations, and soft-tissue injuries in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*).

Variable	Fracture			Laceration			Soft-tissue injury		
	OR[a]	95% CI	p-value	OR[a]	95% CI	p-value	OR[a]	95% CI	p-value
Sex									
Dog	Ref			Ref			Ref		
Bitch	0.83	0.68-1.00	0.05	0.87	0.74-1.02	0.08	1.08	1.00-1.16	0.04*
Country of origin									
New Zealand	Ref			Ref			Ref		
Australia	1.59	1.31-1.93	<0.001*	1.49	1.26-1.76	<0.001*	1.10	1.01-1.19	0.02*
Race age (months)									
14-25	Ref						Ref		
26-31	1.42	1.07-1.87	0.02*				1.17	1.05-1.30	<0.001*
32-38	1.76	1.33-2.31	<0.001*				1.42	1.27-1.58	<0.001*
39-77	1.79	1.36-2.35	<0.001*				1.80	1.63-1.99	<0.001*
Career start number									
1-13 starts				Ref					
14-28 starts				0.96	0.77-1.20	0.71			
29-51 starts				0.89	0.72-1.12	0.33			
51-231 starts				1.12	0.91-1.39	0.27			

Days since previous race									
<7	Ref			Ref			Ref		
7	1.17	0.94-1.47	0.16	0.89	0.74-1.07	0.20	0.90	0.83-0.99	0.02*
>7	1.40	1.12-1.74	<0.001*	0.93	0.77-1.12	0.42	1.11	1.02-1.21	0.01*
Race type									
Sprint	Ref			Ref			Ref		
Middle	0.91	0.75-1.11	0.36	0.94	0.79-1.11	0.44	0.89	0.82-0.96	<0.001*
Distance	1.24	0.68-2.26	0.49	1.47	0.91-2.35	0.11	0.81	0.61-1.07	0.14
Race grade									
Class 1	Ref			Ref			Ref		
Class 0	0.83	0.60-1.14	0.24	1.03	0.81-1.32	0.79	0.96	0.86-1.07	0.44
Class 2	1.06	0.80-1.41	0.67	1.16	0.93-1.46	0.19	1.10	0.99-1.22	0.07
Class 3	1.28	0.94-1.73	0.11	1.23	0.95-1.59	0.11	0.97	0.86-1.09	0.59
Class 4	1.41	1.02-1.96	0.04	0.90	0.65-1.24	0.52	0.96	0.84-1.11	0.61
Class 5	1.80	1.36-2.39	0.00	1.43	1.11-1.85	0.01	0.84	0.74-0.96	0.01*
Other [b]	0.94	0.52-1.69	0.83	1.03	0.64-1.65	0.91	0.76	0.60-0.96	0.02*
Racetrack									
Track A	Ref			Ref			Ref		
Track B	0.60	0.36-0.99	0.05	0.81	0.54-1.21	0.30	0.74	0.57-0.96	0.02*
Track C	1.33	1.01-1.75	0.04*	1.64	1.30-2.07	<0.001*	2.61	2.29-2.97	<0.001*
Track D	0.99	0.77-1.26	0.92	1.19	0.96-1.47	0.11	3.36	3.01-3.75	<0.001*
Track E	0.82	0.57-1.18	0.28	1.06	0.79-1.43	0.70	1.68	1.43-1.97	<0.001*
Track F	0.72	0.46-1.14	0.17	0.54	0.34-0.86	0.01*	0.87	0.68-1.11	0.27
Track G	0.82	0.58-1.14	0.23	1.12	0.86-1.47	0.39	3.79	3.36-4.29	<0.001*

Starting box									
1	Ref			Ref			Ref		
2	1.51	1.00-2.29	0.05	1.06	0.76-1.46	0.74	1.05	0.91-1.21	0.48
3	1.69	1.12-2.53	0.01*	1.23	0.90-1.69	0.19	1.03	0.90-1.19	0.64
4	1.52	1.00-2.30	0.05	1.23	0.90-1.68	0.20	1.02	0.89-1.17	0.77
5	1.66	1.10-2.50	0.02*	1.16	0.85-1.60	0.35	0.97	0.84-1.11	0.63
6	1.57	1.04-2.38	0.03*	1.39	1.02-1.88	0.04*	0.98	0.85-1.13	0.80
7	1.52	1.00-2.30	0.05	1.06	0.76-1.46	0.74	0.89	0.77-1.03	0.12
8	1.95	1.31-2.90	<0.001*	0.93	0.67-1.30	0.68	0.87	0.75-1.01	0.07
Season									
Winter	Ref			Ref			Ref		
Spring	1.17	0.90-1.53	0.25	1.13	0.91-1.40	0.26	0.95	0.86-1.05	0.33
Summer	1.20	0.93-1.57	0.17	0.93	0.75-1.16	0.53	0.96	0.87-1.06	0.46
Autumn	1.34	1.04-1.74	0.03*	1.02	0.82-1.27	0.85	0.88	0.79-0.97	0.01*
Race year									
2018/2019	Ref			Ref			Ref		
2019/2020	0.84	0.63-1.13	0.25	1.19	0.94-1.52	0.16	1.19	1.08-1.32	<0.001*
2017/2018	0.83	0.63-1.11	0.21	0.97	0.75-1.24	0.78	0.72	.0.65-0.81	<0.001*
2016/2017	0.92	0.69-1.22	0.56	0.90	0.70-1.17	0.44	0.63	0.55-0.71	<0.001*
2015/2016	0.99	0.74-1.34	0.97	1.21	0.94-1.56	0.15	0.89	0.79-1.00	0.05*
2014/2015	1.10	0.73-1.66	0.64	1.24	0.87-1.77	0.24	0.64	0.53-0.78	<0.001*

[a] OR: Odds ratio

[b] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

5.4.1 Fracture

The results for univariable screening of potential risk factors for fractures are presented in Table 5.3. The sex of the dog, country of origin, age at time of racing start, days since previous race start, race grade, racetrack, starting box position and season were selected for inclusion in the multivariable model. The final multivariable model for the outcome of fracture is presented in Table 5.4. No interaction terms were significant. After adjusting for the other variables in the model, the odds of fracture were higher in Australian dogs racing in New Zealand compared with New Zealand dogs. Greyhounds in the older age categories had a greater odds of fracture compared with the younger baseline group (14-25 months). The odds of fracture were higher for dogs that had not raced in the previous seven days compared with those that had less than seven days since their previous race. There were increased odds of fracture for dogs racing in class 5 compared to class 1 races. Increased odds of fracture were observed in dogs starting from all boxes compared to box 1, and if the dog started from box 8, the odds of fracture was nearly two times that of dogs starting from box 1 (OR: 1.95, 95% CI: 1.31-2.90).

The fit of the model was assessed by residual values and the residual values had a median of 0.0026 (IQR: 0.0020-0.0034) and 0.0028 (IQR: 0.0021-0.0037) for starts without a fracture and those with a fracture occurring, respectively.

Table 5.4 Multivariable logistic regression results of risk factors for fractures in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*).

Variable	Category	Coefficient	SE[a]	Adjusted OR[b]	95% CI Lower	95% CI Upper	p-value
Country of origin							
	New Zealand	Ref					
	Australia	0.41	0.12	1.50	1.20	1.88	<0.001*
Race age (months)							
	14-25	Ref					
	26-31	0.23	0.15	1.26	0.94	1.70	0.12
	32-38	0.36	0.15	1.44	1.06	1.94	0.02*
	39-77	0.37	0.16	1.45	1.07	1.97	0.02*
Days since previous race							
	<7	Ref					
	7	0.13	0.12	1.14	0.90	1.44	0.28
	>7	0.29	0.12	1.33	1.06	1.67	0.01*
Race grade							
	Class 1	Ref					
	Class 0	-0.11	0.17	0.90	0.65	1.24	0.51
	Class 2	0.06	0.15	1.06	0.8	1.42	0.67
	Class 3	0.24	0.16	1.27	0.93	1.72	0.13
	Class 4	0.31	0.17	1.37	0.98	1.91	0.07
	Class 5	0.49	0.15	1.63	1.21	2.19	<0.001*
	Other [c]	-0.01	0.30	0.99	0.55	1.80	0.97

Starting box							
	1	Ref					
	2	0.42	0.21	1.52	1.00	2.30	0.05
	3	0.52	0.21	1.68	1.12	2.53	0.01*
	4	0.42	0.21	1.52	1.00	2.31	0.05
	5	0.51	0.21	1.67	1.11	2.51	0.01*
	6	0.45	0.21	1.57	1.04	2.38	0.03*
	7	0.42	0.21	1.52	1.00	2.30	0.05
	8	0.67	0.20	1.95	1.31	2.90	<0.001*
Season							
	Winter	Ref					
	Spring	0.15	0.14	1.16	0.88	1.51	0.29
	Summer	0.18	0.14	1.20	0.92	1.57	0.18
	Autumn	0.28	0.13	1.33	1.03	1.72	0.03*

[a] SE : Standard error

[b] OR : Odds ratio

[c] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

The intraclass correlation coefficient, describing the correlation between observations within trainers, was 0.038 (95% CI: 0.016–0.091). This suggests that 3.8% of variation in risk of fracture, unexplained by fixed variables in the model, occurred at the trainer level.

5.4.2 Laceration

The results for univariable screening of potential risk factors for lacerations are presented in Table 5.3. The sex of the dog, country of origin, race type (distance), race grade, racetrack, starting box position and race year were selected for inclusion in the multivariable model. The final multivariable model for the outcome of laceration is presented in Table 5.5. No interaction terms were significant. After adjusting for the other variables in the model, the odds of laceration were higher in Australian dogs compared with the New Zealand dogs. The odds of laceration varied for each race grade compared with class 1. The odds of laceration increased at tracks C and D compared with track A, whereas the odds were decreased at track F compared with track A.

The residual values had a median of 0.0026 (IQR: 0.0020-0.0034) and 0.0033 (IQR: 0.0025–0.0043) for starts without a laceration and those with a laceration occurring, respectively. The low residual values demonstrate that the model was a good fit.

Table 5.5 Multivariable logistic regression results of risk factors for lacerations in racing greyhounds in New Zealand. Statistically significant variables ($p<0.05$) are marked with (*).

Variable	Category	Coefficient	SE[a]	Adjusted OR[b]	95% CI		p-value
					Lower	Upper	
Country of origin							
	New Zealand	Ref					
	Australia	0.35	0.10	1.42	1.17	1.73	<0.001*
Race grade							
	Class 1	Ref					
	Class 0	0.10	0.13	1.10	0.86	1.41	0.45
	Class 2	0.14	0.12	1.15	0.91	1.45	0.24
	Class 3	0.19	0.13	1.21	0.93	1.56	0.15
	Class 4	-0.13	0.17	0.88	0.63	1.22	0.43
	Class 5	0.33	0.14	1.39	1.07	1.82	0.02*
	Other[c]	0.10	0.24	1.10	0.69	1.78	0.68

Racetrack							
	Track A	Ref					
	Track B	-0.18	0.21	0.83	0.56	1.25	0.38
	Track C	0.54	0.15	1.72	1.27	2.32	<0.001*
	Track D	0.28	0.14	1.32	1.01	1.73	0.04*
	Track E	0.08	0.18	1.09	0.76	1.54	0.65
	Track F	-0.53	0.25	0.59	0.36	0.96	0.03*
	Track G	0.20	0.17	1.23	0.89	1.69	0.22

[a] SE : Standard error
[b] OR : Odds ratio
[c] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

The intraclass correlation coefficient for the intra-trainer level variation was 0.045 (95% CI: 0.023–0.086), that is, 4.5% of the total unexplained variation in risk of laceration was attributable to unmeasured trainer-level effects.

5.4.3 Soft-tissue injury

The results for univariable screening of potential risk factors for soft-tissue injury are presented in Table 5.3. The sex of the dog, country of origin, age at time of racing start, days since previous race start, race type (distance), race grade, racetrack, starting box position, season and race year were selected for inclusion in the multivariable model. The multivariable model for the outcome of soft-tissue injuries is presented in Table 5.6. No interaction terms were significant. After accounting for the other variables in the model, the odds of soft-tissue injuries were increased for dogs aged between 39 and 77 months compared with those aged 14 and 25 months and the odds were decreased for dogs racing once a week compared to more than once a week. The odds of a soft-tissue injury occurring was increased for dogs in maiden races (class 0), compared with those in class 1. The odds of a soft-tissue injury varied for the different tracks; there was an increased odds of soft-tissue injury at track C, track D and track G compared with track A. There was variation in the odds of soft-tissue injury across the different racing years, in particular with the 2019/2020 season having an increased odds compared with the 2018/2019 racing season while the 2014/2015, 2016/2017 and 2017/2018 seasons all had a decreased odds compared to the 2018/2019 season.

Goodness of fit was assessed by examining the residual values. The residual values had a median of 0.0026 (IQR: 0.0020-0.0034) and 0.0028 (IQR: 0.0023-0.0037) for starts without a soft-tissue injury and those with a soft-tissue injury occurring, respectively.

Table 5.6 Multivariable logistic regression results of risk factors for soft-tissue injuries in racing greyhounds in New Zealand. Statistically significant variables (p<0.05) are marked with (*).

Variable	Category	Coefficient	SE[a]	Adjusted OR[b]	95% CI		p-value
					Lower	Upper	
Race age (months)							
	14-25	Ref					
	26-31	0.62	0.06	1.06	0.95	1.19	0.29
	32-38	0.22	0.06	1.25	1.11	1.41	<0.001*
	39-77	0.44	0.06	1.55	1.37	1.75	<0.001*
Days since previous race							
	<7	Ref					
	7	-0.13	0.05	0.87	0.80	0.96	<0.001*
	>7	0.06	0.05	1.07	0.97	1.16	0.17
Race distance type							
	Sprint	Ref					
	Middle	-0.01	0.04	0.99	0.91	1.08	0.87
	Distance	-0.31	0.15	0.73	0.55	0.99	0.04*
Race grade							
	Class 1	Ref					
	Class 0	0.20	0.06	1.22	1.08	1.37	<0.001*
	Class 2	0.07	0.05	1.07	0.97	1.19	0.19
	Class 3	-0.28	0.06	0.97	0.86	1.10	0.67
	Class 4	-0.01	0.07	0.99	0.85	1.14	0.84
	Class 5	-0.14	0.07	0.87	0.76	1.01	0.07
	Other[c]	-0.05	0.12	0.95	0.75	1.22	0.71

Racetrack							
	Track A	Ref					
	Track B	-0.27	0.14	0.76	0.58	1.00	0.05
	Track C	0.94	0.10	2.56	2.12	3.10	<0.001*
	Track D	1.23	0.08	3.44	2.94	4.02	<0.001*
	Track E	0.55	0.11	1.73	1.40	2.13	<0.001*
	Track F	-0.07	0.13	0.94	0.73	1.21	0.61
	Track G	1.46	0.09	4.31	3.65	5.10	<0.001*
Season							
	Winter	Ref					
	Spring	-0.09	0.05	0.91	0.82	1.01	0.01*
	Summer	-0.06	0.05	0.94	0.85	1.04	0.23
	Autumn	-0.11	0.05	0.90	0.81	0.99	0.03*
Race year							
	2018/2019	Ref					
	2019/2020	0.23	0.05	1.26	1.14	1.40	<0.001*
	2017/2018	-0.30	0.06	0.74	0.66	0.83	<0.001*
	2016/2017	-0.43	0.06	0.65	0.57	0.74	<0.001*
	2015/2016	-0.02	0.06	0.98	0.87	1.11	0.79
	2014/2015	-0.26	0.10	0.77	0.63	0.95	0.01*

[a] SE : Standard Error
[b] OR : Odds ratio
[c] Other race grades include races in invited series, age restricted races, and special races where conditions of entry must be met but no specific race grade applies.

The intraclass correlation coefficient, describing the correlation between observations within trainers, was 0.041 (95%CI: 0.026–0.062). This suggests that 4.1% of variation in risk of fracture, unexplained by fixed variables in the model, occurred at the trainer level.

5.5 DISCUSSION

This study is the first to provide an assessment of the three most common injury categories that occur during racing: soft-tissue injuries, lacerations and fractures and has identified risk factors associated with these racing injuries in greyhounds in New Zealand. Injury types were analysed separately as I hypothesised that the aetiology and distribution of soft-tissue injuries, fractures and lacerations would differ greatly. The distribution of injuries in this study was similar to that described by Beer (2014). These results were not unexpected, given that the structure and style of racing is similar in New Zealand and Australia. The most common injuries were reported as soft-tissue injuries, with most of these being classed as "moderate" severity (injuries requiring a stand-down period of 7–20 days). Although there were fewer fractures compared with lacerations and soft-tissue injuries, more than 95% were classed as either severe injuries (21 day stand-down or more) or required euthanasia, suggesting a greater impact of a fracture on the future of the dogs racing career.

Greyhounds' that had a lower racing frequency had greater odds of fracture, which agrees with an earlier study examining injury risk and number of starts in the previous 60 days (Stevenson et al., 2009). However, historically there have been fewer opportunities for greyhounds to race (Stevenson et al., 2009; Palmer et al., 2020a). In New Zealand, greyhounds have a consistent racing schedule with little variation in when dogs have a racing start. For this reason, investigating the association between time since previous racing start and risk of fracture provided information within a relevant timeframe. While I considered modelling in a similar manner to a previous study from New Zealand (number of racing starts in the previous 60 days) (Stevenson et al., 2009), the number of days since the previous racing start and the time-varying variables were collinear and days since the previous racing starts was nested within each of the time-varying variables. Therefore, investigating time between consecutive racing starts was considered more relevant for analysing racing frequency because it was more likely to reflect the pathophysiology of the injury.

The accumulation of load and frequency of load sustained during training and racing exercise is implicated in the pathophysiology of bone injuries across a number of species; including racing greyhounds (Tomlin et al., 2000; Thompson et al., 2012). The nature of the resulting bone remodelling depends upon the magnitude and frequency of the load (Rogers et al., 2007; Martig et al., 2013; Shaktivesh et al., 2020). The results from this study showed that the risk of fracture was associated with the greyhounds with the least racing-intensity exercise accumulated, as measured by more than seven days between consecutive racing starts. This could be due to the requirement for bone to receive appropriate "specific" strain that reflects the load experienced during racing and high-intensity exercise (Boyde & Firth, 2005; Firth et al., 2005; Whitton et al., 2010). The appropriate load is a balance between the total volume of high-speed exercise, the rate at which this exercise is accumulated, and the recovery periods that allow adaptation of bones without reaching the fatigue life of the bone (Martig et al., 2014; Morrice-West et al., 2020). Analysing the time period between consecutive racing starts provided temporal relevance indicating what had occurred around the time of the race. Increased risk of fracture in racing due to greater time between consecutive races was likely exacerbated by a survival bias (Parkin, 2008), where the dogs that were not racing at least once a week were those that already had, or were prone to, health complications or had prior ailments. Previous injuries were not specifically investigated in this study, which may be a confounding factor for the association between fewer races in the previous seven days and the risk of fracture.

The age of the greyhound at the time of the race start indirectly represented cumulative load, and this study found that older dogs had a greater odds of fracture compared to younger dogs. In New Zealand, greyhounds begin training and racing at a similar age (Palmer et al., 2020a; Palmer et al., 2020b) and have a consistent training programme based around the opportunity to race at least once a week (Palmer et al., 2020b). Given this, older greyhounds had a higher risk of fracture compared to younger greyhounds due to the cumulative exposure to high-intensity load cycles. This result is in agreement with existing literature (Stevenson et al., 2009; Beer, 2014), where increased age has been associated with racing injuries and serious tarsal injury in racing greyhounds.

Sicard et al. (1999) previously reported that the injury rate in racing greyhounds increased as the grade of the race increased. In this study, dogs performing in a higher race grade (class five) were identified as having a greater risk of fracture compared with the class one dogs. There was also an increased odds of fracture for Australian dogs compared to New Zealand dogs, in part driven by only quality (high performing in terms of maximum race grade reached) dogs being imported from Australia and Australian whelped greyhounds being older than New Zealand greyhounds (Palmer et al., 2020a). Although race speed data was not provided, racing class indirectly signal the association of racing speed and accumulated load cycles with the risk of fracture. Faster winning race speeds are associated with increasing injury risk (Sicard et al., 1999; Stevenson et al., 2009), and speed has been well documented as a risk factor for musculoskeletal injury in racehorses (Estberg et al., 1998; Cogger et al., 2006; Verheyen et al., 2006; Parkin, 2008). The association between speed and risk of fracture has been attributed to the increased forces and torque applied to the limbs with increased speed in racehorses (Harrison et al., 2010). Over numerous load cycles the increased force results in increased microdamage (Danova et al., 2003; Martig et al., 2014). The increased odds of fracture with Australian dogs reflects the higher racing grade (only high grade or high grade potential dogs are imported (Palmer et al., 2020a)), the older age of Australian dogs (Palmer et al., 2020a), and the previously described effect of increased strain at higher racing speeds as well as increased load cycles experienced by these higher grade dogs.

This study identified starting box number as a risk factor for fractures which has not been previously reported. In New Zealand, the lure is on the inside rail, which is closest to starting box number one and furthest away from box number eight (which presented higher odds of fracture). The most likely hypothesis is a combination of the field of dogs galloping after the one lure, as well as the physical orientation and properties of the track. In conjunction, these alter the opportunities for greyhounds to obtain their desired path by the time they reach the first bend which is also where the greyhounds are travelling the fastest (Hayati et al., 2017; Hossain et al., 2019) and most injuries occur (Bloomberg & Dugger, 1998; Auer, 1999; Sicard et al., 1999;

Eager et al., 2017). However, speed, track properties and the location of injuries on the track were not specifically investigated in this study, suggesting that further work is required to determine if the impact of starting box number can be modified to reduce future injuries.

As with any athletic endeavour, there is always some level of risk of injury. Early identification and appropriate interventions of greyhounds with an increased risk of injury, could reduce the physical, emotional, and economic impact of injuries in racing greyhounds. Further reduction in the incidence of fractures within the racing industries may require development of more sensitive clinical imaging modalities and possibly identification of physiological biomarkers to improve screening and identify greyhounds at greater risk.

I hypothesise that risk factors that were significantly associated with lacerations pertain primarily to environmental factors, as a greyhound must have come in contact with an object or another greyhound in order to sustain a laceration. For example, I hypothesised that a number of the lacerations occurred at the end of the race when the greyhounds congregated at the lure where jostling and interference occur. At the end of a race, when the lure decelerated, the greyhounds were able to finish on the lure, resulting in the field of dogs within close proximity all competing for one target as well as the metal lure arm and rail on which the lure transverses. We are suggesting that jostling and interference during the time at which the dogs were allowed on the lure, resulted in lacerations. Recent studies have investigated path trajectories with different length lure arms (Mahdavi et al., 2018) and it may be useful for future work to consider the effect of a larger or different style of lure to help mitigate some of these injuries. However, it should be noted that the location of the injury on the track was not accurately recorded in the dataset used in this study. Such data would be useful to allow more investigation of the locations that have higher risks of injury, which may enable modifications to made to reduce injury risk.

Soft-tissue injuries sustained by greyhounds during a race were predominantly muscle injuries with a relatively short stand-down period imposed. There was a lack of specificity in how the soft-tissue injury data were reported and this limited precise description of the different muscle, tendon, and ligament injuries. However, the relatively short stand-down periods (typically 1–20 days) assigned to the soft-tissue category of injuries suggest that most were muscular (not tendon or ligament). Such injuries could be considered a by-product of athletic pursuit, and the level to which they were detected demonstrates the sensitivity of veterinary examination to identifying soft-tissue injuries. It is hard to determine what soft-tissue injury was sustained as the information on the specific anatomical location of the injury was not provided in the database. There is a need for a more specific case definition of soft-tissue injuries to be described if potential risk-factors for muscle, tendon and ligament injuries are to be examined and misclassification bias is to be minimised.

The general trend for increasing odds of soft-tissue injury with increasing age seen in this study is consistent with findings from other racing animal models (Perkins et al., 2005a, 2005b). Additionally, the occurrence of musculoskeletal injuries is known to increase with age in military working dogs (Mey et al., 2020) and agility dogs (Kerr et al., 2014). The association with age could be attributed to accumulated cyclic load and the changes in the regenerative potential of the affected tissues as the greyhound matures. A classic example of this interaction of cyclic load and changing tissue properties and regenerative potential is the loss of structural integrity of tendons associated with the ageing process reported in Thoroughbred racehorses (Patterson-Kane et al., 1997; Smith et al., 1999). Moreover, because the workload of racing greyhounds is consistent and highly repeatable, without consistent rest or spell periods (Palmer et al., 2020b), the risk of injury continues to increase, even though there is no increase in the weekly training volume.

The association between racetrack and injuries in greyhounds has been previously noted (Sicard et al., 1999; Iddon et al., 2014; Eager et al., 2017; Eager et al., 2018; Mahdavi et al., 2018). Track related parameters, including the track radius, angle of banking and the track surface, predispose greyhounds to specific injuries (Sicard et al., 1999; Iddon et al., 2014; Eager et al., 2018; Hayati et al., 2020). However, this study found no clear pattern between tracks and odds of soft-tissue injuries in this study, despite the tracks having different geometries. Clustering at a regional level may be due to the different personnel (Stipendiary Stewards and on-track veterinarians) at different racetracks and their level of reporting and inspection of greyhounds, rather than track configuration. For example, tracks D and G are located in the same region and despite the two tracks having different geometric features, they had a similar odds of soft-tissue injury compared to track A. This variation in soft-tissue injuries could, in part, be explained by the same personnel working at racetracks in similar areas, as well as the different personnel throughout New Zealand having a different interpretation on the level of precision and recording required for injury reporting. The lack of robust methods for injury detection and reporting, as well as potential misclassification could explain the differences in odds of soft-tissue injury at the difference racetracks.

The greyhound racing industry in New Zealand should look to moving towards a more detailed standardised injury reporting scheme which would provide more precise and descriptive details of the injuries sustained during racing. The broad description of the type and location of injuries needs to be improved to provide more robust data to describe the incidence of anatomically specific injuries so that the incidence and associated risk factors can be determined. The increase in soft-tissue injuries in the 2019/2020 racing season compared with the 2018/2019 season may be attributed to improvements in the intensity of injury surveillance and the efficiency of data capture having improved over time. It is important to consider the potential bias in the detection, diagnosing and reporting of racing injuries, attributable to the methods of data collection and consistency of reporting (Palmer et al., 2021).

5.6 CONCLUSIONS

Soft-tissue injuries, lacerations and fractures were the three most common injuries of racing greyhounds in New Zealand in this study. The identification of these three injuries allowed specific risk factors to be analysed for each outcome. This research demonstrated that fractures had a greater impact than soft-tissue injuries, however, fractures occurred at a lower frequency. To obtain a better understanding of the injuries associated with racing in New Zealand and in order to proactively manage racing greyhounds, efforts should be focused into improving the precision at which injuries are detected and reported. This study found that dogs racing less frequently were more likely to sustain a fracture, the odds of fracture increased with increasing race speed and the odds of fracture were higher in older greyhounds compared with younger greyhounds. As in many forms of competitive sports, injuries are an inherent element of racing and in order to reduce the incidence rate of injuries, more thorough diagnostic tools are required for detection. To reduce the rate of injuries in racing greyhounds, efforts should be focused into investigating and screening those greyhounds who have not raced frequently. Early detection of injuries may help to identify dogs that are at risk of sustaining a racing injury. This study provides a useful benchmark from which to assess the effectiveness of future strategies implemented by the industry.

REFERENCES

Auer, D., E. (1999). *Prevalence and type of injuries to racing greyhounds in South East Queensland.* World Greyhound Racing Federation Conference 2000, Sydney.

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190.

Bloomberg, M., & Dugger, W. (1998). Greyhound racing injuries: racetrack injury survey. In: M. S. Bloomberg, J. F. Dee, and R.A. Taylor (Eds.), *Canine sports medicine and surgery* (pp. 412-415). W.B. Saunders Company, Philadelphia, United States of America.

Boyde, A., & Firth, E. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 8. Quantitative back-scattered electron scanning electron microscopy and confocal fluorescence microscopy of the epiphysis of the third metacarpal bone. *New Zealand Veterinary Journal*, *53*(2), 123-132.

Cogger, N., Perkins, N., Hodgson, D., Reid, S., & Evans, D. (2006). Risk factors for musculoskeletal injuries in 2-year-old Thoroughbred racehorses. *Preventive Veterinary Medicine*, *74*(1), 36-43.

Cook, A. (1998). Literature survey of racing greyhound injuries, performance and track conditions. *Journal of Turfgrass Science*, *74*, 108-113.

Danova, N., Colopy, S., Radtke, C., Kalscheur, V., Markel, M., Vanderby Jr, R., McCabe, R., Escarcega, A., & Muir, P. (2003). Degradation of bone structural properties by accumulation and coalescence of microcracks. *Bone*, *33*(2), 197-205.

Davis, P. (1973). Toe and muscle injuries of the racing greyhound. *New Zealand Veterinary Journal*, *21*(7), 133-146.

Dohoo, I. R., Martin, W., & Stryhn, H. E. (2009). *Veterinary Epidemiologic Research* (2nd ed.). VER Inc. Charlottetown, Canada.

Eager, D., Hayati, H., & Hossain, M. (2017). *Identifying optimal greyhound track design for greyhound safety and welfare. Phase I Report January 2016 to 31 December 2016*. University of Technology Sydney.

Eager, D., Hayati, H., Mahdavi, F., Hossain, M., Stephenson, R., & Thomas, N. (2018). *Identifying optimal greyhound track design for greyhound safety and welfare-Phase II-Progress Report-1 January 2016 to 31 December 2017*. University of Technology Sydney.

Estberg, L., Gardner, I. A., Stover, S. M., & Johnson, B. J. (1998). A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California Thoroughbred racehorses. *Preventive Veterinary Medicine, 33*(1-4), 159-170.

Firth, E., Rogers, C., Doube, M., & Jopson, N. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 6. Bone parameters in the third metacarpal and third metatarsal bones. *New Zealand Veterinary Journal*, *53*(2), 101-112.

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association. https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf

Harrison, S. M., Whitton, R. C., Kawcak, C. E., Stover, S. M., & Pandy, M. G. (2010). Relationship between muscle forces, joint loading and utilization of elastic strain energy in equine locomotion. *Journal of Experimental Biology*, *213*(23), 3998-4009.

Hayati, H., Eager, D., Peham, C., & Qi, Y. (2020). Dynamic Behaviour of High Performance of Sand Surfaces Used in the Sports Industry. *Vibration*, *3*(4), 410-424.

Hayati, H., Eager, D., Stephenson, R., Brown, T., & Arnott, E. (2017). The impact of track related parameters on catastrophic injury rate of racing greyhounds. In *9th Australasian Congress on Applied Mechanics* (pp 311-317). Sydney Engineers Australia.

Hosmer, D.W. and Lemeshow, S. (2000). *Applied logistic regression*. Wiley-Interscience, New York, USA.

Hossain, M. I., Eager, D., & Walker, P. (2019). Simulation of racing greyhound kinematics. *Proceedings of the SIMULTECH 2019 - 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (pp 47 – 56), Prague, Czech Republic.

Iddon, J., Lockyer, R., & Frean, S. (2014). The effect of season and track condition on injury rate in racing greyhounds. *Journal of Small Animal Practice, 55*(8), 399-404.

Kerr, Z. Y., Fields, S., & Comstock, R. D. (2014). Epidemiology of injury among handlers and dogs competing in the sport of agility. *Journal of Physical Activity and Health*, *11*(5), 1032-1040.

Mahdavi, F., Hossain, M. I., Hayati, H., Eager, D., & Kennedy, P. (2018). Track shape, resulting dynamics and injury rates of greyhounds. *Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition*. *Volume 13: Design, Reliability, Safety, and Risk*. Pittsburgh, Pennsylvania, USA. The American Society of Mechanical Engineers.

Martig, S., Chen, W., Lee, P., & Whitton, R. (2014). Bone fatigue and its implications for injuries in racehorses. *Equine Veterinary Journal*, *46*(4), 408-415.

Martig, S., Lee, P. V., Anderson, G. A., & Whitton, R. C. (2013). Compressive fatigue life of subchondral bone of the metacarpal condyle in thoroughbred racehorses. *Bone*, *57*(2), 392-398.

Mey, W., Schuh-Renner, A., Anderson, M. K., Stevenson-LaMartina, H., & Grier, T. (2020). Risk factors for injury among military working dogs deployed to Iraq. *Preventive Veterinary Medicine*, *176*, 104911.

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

Palmer, A., Rogers, C., Stafford, K., Gal, A., & Bolwell, C. (2021). A retrospective descriptive analysis of race-day injuries of greyhounds in New Zealand. *Australian Veterinary Journal*, *99*(6), 255-262.

Palmer, A. L., Bolwell, C. F., Stafford, K. J., Gal, A., & Rogers, C. W. (2020a). Patterns of racing and career duration of racing greyhounds in New Zealand. *Animals*, *10*(5), 796.

Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., Cochrane, D. J., & Bolwell, C. F. (2020b). Cross-sectional survey of the training practices of racing greyhounds in New Zealand. *Animals*, *10*(11), 2032.

Parkin, T. D. (2008). Epidemiology of racetrack injuries in racehorses. *Veterinary Clinics of North America: Equine Practice, 24*(1), 1-19.

Patterson-Kane, J., Firth, E., Goodship, A., & Parry, D. (1997). Age-related differences in collagen crimp patterns in the superficial digital flexor tendon core region of untrained horses. *Australian Veterinary Journal*, *75*(1), 39-44.

Perkins, N., Reid, S., & Morris, R. (2005a). Risk factors for injury to the superficial digital flexor tendon and suspensory apparatus in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 184-192.

Perkins, N., Reid, S., & Morris, R. (2005b). Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*, *53*(3), 171-183.

Rogers, C., Rivero, J., Van Breda, E., Lindner, A., & van Oldruitenborgh-Oosterbaan, M. S. (2007). Describing workload and scientific information on conditioning horses. *Equine and Comparative Exercise Physiology*, *4*(1), 1-6.

Shaktivesh, S., Malekipour, F., Whitton, R. C., Hitchens, P. L., & Lee, P. V. (2020). Fatigue behavior of subchondral bone under simulated physiological loads of equine athletic training. *Journal of the Mechanical Behavior of Biomedical Materials*, *110*, 103920.

Sicard, G., Short, K., & Manley, P. (1999). A survey of injuries at five greyhound racing tracks. *Journal of Small Animal Practice*, *40*(9), 428-432.

Smith, R., Birch, H., Patterson-Kane, J., Firth, E., Williams, L., Cherdchutham, W., WEEREN, W. v., & Goodship, A. (1999). Should equine athletes commence training during skeletal development?: changes in tendon matrix associated with development, ageing, function and exercise. *Equine Veterinary Journal*, *31*(S30), 201-209.

Snijders, T. A., & Bosker, R. (2011). *Multilevel analysis: An introduction to basic and advanced multilevel modeling*. Sage Publications, London, England.

Stevenson, M., Stafford, K., & Cave, N. (2009). *Risk factors for injury in New Zealand racing greyhounds*: *A report prepared for the New Zealand Racing Greyhound Association.* Massey University.

Thompson, D., Cave, N., Bridges, J., Reuvers, K., Owen, M., & Firth, E. (2012). Bone volume and regional density of the central tarsal bone detected using computed tomography in a cross-sectional study of adult racing greyhounds. *New Zealand Veterinary Journal, 60*(5), 278-284.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International, 67*(3), 260-266.

Verheyen, K., Price, J., Lanyon, L., & Wood, J. (2006). Exercise distance and speed affect the risk of fracture in racehorses. *Bone*, *39*(6), 1322-1330.

Whitton, R. C., Trope, G. D., Ghasem-Zadeh, A., Anderson, G. A., Parkin, T. D., Mackie, E. J., & Seeman, E. (2010). Third metacarpal condylar fatigue fractures in equine athletes occur within previously modelled subchondral bone. *Bone*, *47*(4), 826-831.

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.

Chapter 6 GENERAL DISCUSSION

This thesis presents the results of a series of studies contributing to the understanding of the training and racing of greyhounds in New Zealand. The motivation for the research was the anecdotally high injury and death rates, short racing career lengths and the high frequency of racing. While these factors constituted public concerns about the industry, empirical evidence of practices within the greyhound racing industry were sparse in the scientific literature, The research presented in this thesis addresses societal concerns about greyhound welfare and provides evidence that can be used to implement strategies to minimise the involuntary loss of greyhounds from the industry,

The order in which the research was undertaken was considered and it was critical that the initial studies provided the scope and an understanding of the industry through quantifying racing patterns and career profiles. This initial work helped to inform the subsequent study which investigated training practices and workload of racing greyhounds. The results from the first two studies were utilised when designing the methods and analysing injuries sustained during racing. Employing both Poisson and logistic regression methods provided complementary and beneficial insights when analysing racing injuries. Poisson regression allowed for the analysis of injury rates and provided a more nuanced understanding of injury incidence. The results from the study investigating frequency of injuries were then utilised when building the logistic regression model, which was used to provide insight into the probability of injury occurrence. Odds ratios obtained from logistic regression aid in understanding the relationship and strength of associations between predictor variables and the likelihood of injury. Using both Poisson and logistic methods permitted a comprehensive analysis and allowed different aspects of the injury data to be explored; count data trends and the likelihood of sustaining injuries. Results from both the Poisson and logistic regression analysis were compared to validate the findings and ensure robustness in the conclusions drawn. Through understanding both the incidence (Poisson) and the probability (logistic) of injuries, interventions aimed to reduce injuries can be more effectively targeted.

The analyses in Chapters 2, 4 and 5 were based on pre-existing racing industry records collected by Greyhound Racing New Zealand. While the use of retrospective data provided a large sample size without the need for substantial time and resources in data collection, there were limitations using the data beyond its original intentions. As a consequence, results were subject to underestimation and potential misclassification of both the type and frequency of injuries sustained by racing greyhounds. The manner in which data were captured and recorded within the industry restricted the range of race level variables analysed and the precision of injury data.

6.1 OVERVIEW OF RESULTS

The descriptive analyses used to quantify frequency of racing in greyhounds (Chapter 2) identified that greyhounds raced every seven days with very little variation to this pattern. The racing frequency reported in this study was unique to the greyhound code, compared with the other racing codes, for example Thoroughbred horses in New Zealand (Bolwell et al., 2016a, 2016b). The regularity of the greyhound racing industry, in terms of the scheduling and location of race meetings, provided the opportunity for greyhounds to race on a weekly basis.

Previously, training practices of racing greyhounds have been described as exercise protocols used in research studies (Donald et al., 1964; Rippe et al., 1982; Kesl, 1993; Lonsdale et al., 1998; Hill et al., 2001), however, until now, to the author’s knowledge, no detailed training information has been reported at either trainer nor dog level. The training programmes reported in this study identified that greyhounds partook in two to three high-intensity workouts (be it training or racing) each week. The results from the training survey demonstrated that greyhounds were subjected to a workload that consisted of both high-intensity and low-intensity exercise based around a weekly micro-cycle of training and racing. Overall, training programmes were used to condition greyhounds to the stressors of racing, to achieve specificity and to stimulate appropriate physiological adaptations to maintain or improve racing performance. Greyhounds’ ability to maintain a regular racing schedule was likely attributable to their natural athletic ability and physiological capabilities (Dobson et al., 1988; Ilkiw et al., 1989; Rose & Bloomberg, 1989; Kesl, 1993; Bhatt et al., 2011; Pellegrino et al., 2018). Greyhounds possess metabolic, physiological, and anatomical qualities that allow them to store and utilise energy efficiently, remove biochemical toxins proficiently, and return to homeostasis rapidly following high-intensity exercise (Guy & Snow, 1981; Dobson et al., 1988; Ilkiw et al., 1989; Rose & Bloomberg, 1989; Kesl, 1993; Pellegrino et al., 2018). The training programmes were tailored to short duration bouts of anaerobic metabolism, which imitated the physiological requirements during racing. High-intensity training sessions were used as a method to condition greyhounds and the periods of low-intensity work that occurred between the load cycles provided an active form of recovery. The results showed that, typically, the design of the training programmes incorporated exercise that conditioned greyhounds to the physiological stresses involved in racing.

The results from the study in Chapter 2 provided new information documenting the career duration and descriptive statistics for career milestones of racing greyhounds in New Zealand. Greyhounds typically had 35 racing starts in their active career, which spanned over a median 424 days (IQR: 206-647 days). The number of racing starts was higher than research from Victoria, Australia, where greyhounds recorded a median of 10 starts across a six-year study period (Beer, 2014). Reasons for the difference in number of racing starts between Victoria and New Zealand may be due to the opportunities to race dogs being more readily available in New Zealand rather than the competitive environment of racing in Victoria, or may be due to dogs racing inter-state in Australia, where greyhound racing takes place in seven jurisdictions, and thus starts were not included in Beer's data (Beer, 2014).

Overall, career duration varied depending on the predominant interval between races. greyhounds with a greater proportion of high-intensity racing intervals (1–4 days between consecutive races) had more racing starts during their career. Providing dogs more opportunities to race during their career would maximise the potential financial return for each racing greyhound. Career length (in days) was shorter for greyhounds with either predominantly high- or low-intensity racing intervals (11 or more days between consecutive races) compared to dogs that raced on a medium-intensity racing interval (5–10 days between consecutive races) or with no defined racing pattern. There were only a small number of Australian whelped dogs in the low-intensity racing interval group and these dogs had shorter careers and fewer racing starts. Greyhounds racing more frequently over a shorter period of time would have greater potential for monetary return in the time they were racing. To some extent, this result could also have been impacted by the trainers, where some trainers may have had a higher turnover rate of dogs than others but raced their dogs more frequently. In some cases, greyhounds that raced less frequently with a shorter career duration could be due to dogs that had pre-existing problems or injuries and were unable to race as frequently.

Career duration was limited by the age of the dog regardless of the age the dog began racing or the total number of career racing starts. Greyhounds are reported to experience performance decline after peak racing age (Täubert et al., 2007), which could be the result of cumulative injury load (Sicard et al., 1999), decreasing speed and/or the lack of racing success. There was a difference in the age of last race between New Zealand and Australian whelped dogs, the latter finished racing at an older age. This could be due to the quality of the dogs being imported into New Zealand as well as the opportunity to gain more financial return to offset the cost of importing the dogs.

The overall incidence of racing injuries reported in Chapter 4 was similar to a previous report from New Zealand (Stevenson et al., 2009). Improvements in the quality of injury data recorded by GRNZ since 2014 allowed injury specific incidence rates to be examined. Most injuries sustained by racing greyhounds were soft-tissue injuries, however, the implication of these injuries on the ability to continue training and racing was less severe than those for fractures. Most fractures were classed as serious injuries, and the most common reason for greyhounds being euthanased was a fracture.

The distribution of injury stand-down periods prescribed by the race-day veterinarians in this study (Chapter 4) differed from those reported for injuries in Australia (Beer, 2014). The incidence of minor injuries (injuries with a 1-7 day stand-down period) in the present study was 4.6 per 1,000 starts, which was considerably lower than the 19.0 per 1,000 starts as reported by Beer (2014); however the incidence of moderate and serious injuries were similar. Differences in incidence rates between studies may be a result of injury reporting mechanisms and race-day procedures for identifying injured greyhounds. Other factors influencing incidence rates may include differences in track geometry and surface, race-level characteristics, training methods, and variation in study design and case definition (Perkins et al., 2005). These findings highlight that injury surveillance and reporting strategies for racing injuries need to be consistent between different racing jurisdictions if comparisons are to be made and recommendations made for improving the safety of racing.

Although soft-tissue injuries accounted for the largest category of injuries, the reported figures are likely an underestimation of the true level of risk due to the nature of soft-tissue injuries (Parkin, 2008). It is likely that the reported injury rates were underestimated as some dogs would have been diagnosed with injuries in the hours or days after a race given that detection of injuries, based on clinical diagnoses in the period directly after the race can be difficult. Most reported soft-tissue injuries were either moderate or severe as judged by the stand-down period imposed by the veterinarian and so it is possible that not all injuries were detected, as damage to soft-tissue may not require immediate veterinary attention and may have only become discernible after the dog had left the racetrack. Injuries not detected at the racetrack may impact the dog's training, fitness and time taken to return to full health and racing.

The results from Chapter 5 showed that greyhounds racing more frequently had increased odds of soft-tissue injury, which was likely influenced by exposure time for an injury to occur. The number and severity of soft-tissue injuries were consistent with injuries associated with athletic performance. The recovery period between races is crucial for musculoskeletal repair and adaptation. Muscle damage and inflammation accumulated during strenuous exercise (Dupuy et al., 2018) could provide an explanation as to why the risk of soft-tissue injury increased as racing frequency increased. Given that most of the soft-tissue injuries were of moderate or major severity, it is possible that minor racing injuries remained undetected and had the potential to contribute to a more severe injury in a subsequent race.

High-intensity exercise accumulated within a short period of time was protective for the occurrence of fractures. This is in agreement with existing literature (Stevenson et al., 2009), and is likely due to the "healthy-dog" effect where dogs that were not already injured or had pre-existing problems had the ability to race more regularly. The results from Chapter 5 highlight a primary challenge in determining the risk factors for different racing injuries: the ability for a potential risk factor to have distinct effects on different injury types. For example, an increased racing frequency over a certain window of time was protective for fractures but a risk factor for soft-tissue injuries.

The odds of fracture were higher in older dogs compared with younger dogs, however, the increase was not large enough to infer that fractures were the result of fatigue from cyclic compressive loading occurring during high-intensity training and racing. Moreover, the distribution of age at the time of fracture was similar to the distribution of age at race start. This suggests that accumulated overload was not the primary driver for fractures sustained during racing. Nonetheless, asymmetrical cyclic loading injuries of the central tarsal bones and metacarpal bones have been well documented in the literature (Muir et al., 1999; Johnson et al., 2000; Tomlin et al., 2000; Johnson et al., 2001; Thompson et al., 2012), illustrating that these injuries do represent a threat to racing greyhounds. While age has been previously documented as a risk factor for serious tarsal injuries (Beer, 2014) and racing injuries (Stevenson et al., 2009), the difference in results could be attributed to different case definitions for injuries in each study, as well as the way that the variables were categorised and modelled. It could also be due to the frequency of racing being higher in the current study providing the greyhounds with more opportunities for high-intensity exercise on a maintained racetrack and fewer training sessions in more variable training environments.

The natural attrition from racing and the lack of evidence supporting risk of fracture increasing with increasing age suggests that other decision-making processes were involved when retiring the dog from racing. From a biological viewpoint, greyhounds are racing within the constraints of the racing industry. Other factors influence the decision to retire greyhounds, these include a lack of racing ability, decrease in racing performance or other economical considerations.

6.2 IMPLICATIONS AND RECOMMENDATIONS FOR THE GREYHOUND RACING INDUSTRY

The wastage and turnover of racing greyhounds continues to be a concern for the industry and have the potential to threaten the greyhound racing industry's social license to operate (Gunningham et al., 2004). Wastage in the greyhound racing industry is influenced by the relationships between performance, age of the greyhound and the occurrence of injuries. As greyhounds age, the ability to reach peak speeds and peak performance diminishes while the injury rate increases. After a certain age dogs begin to slow and lose competitiveness in the higher grades. The industry has proposed veteran races to allow the older dogs more opportunities to race and prolong the length of their racing careers. However, this study, along with previous research (Stevenson et al., 2009; Beer, 2014) demonstrated that older dogs were at greater risk of soft-tissue injuries and fractures so increasing opportunities to race may not be the answer.

There is potential that the career length of racing greyhounds could be extended. The minimum racing age is regulated by the rules for racing, which was set at 14 months of age. While the regulated minimum racing age has increased to 16 months since these data were collected (Rule 19.10) (Greyhound Racing New Zealand, 2017), the reported age at first race start (median: 20 months) was higher than expected. There is strong evidence that exercise at a young age is beneficial in racing Thoroughbreds (Van Weeren et al., 2008; Firth et al., 2011). The application of appropriate load at an early age stimulates tissue-specific response in magnitude to the loading demands while the musculoskeletal system is most receptive (Warden et al., 2007; Dykgraaf et al., 2008; Warden et al., 2014). The benefits of exercise at an early age are supported by observations that early introduction to training has a positive association with career length and success in racehorses (Bailey et al., 1999; Velie et al., 2013). In Chapter 3, at which time the minimum racing age was 16 months when the data were collected, trainers reported that young dogs commenced training at 12 months of age, speed work at 14 months of age and only required a few gallop-load cycles/trials before they began racing. At present, there is no scientific evidence to support, or dispute, the appropriate load required to stimulate musculoskeletal development and increase the longevity of musculoskeletal health in greyhounds.

This thesis highlighted that more time between consecutive races was associated with higher risk for fracture. Such results place importance on a trainers' decisions as to when to nominate a dog for a racing start. Racing patterns were inherently restricted by opportunities to race. However, the ability to race a dog more frequently (more than once a week), may have been restricted depending on where the trainer was located. Continuing to hold regular race meetings across the country so trainers can nominate greyhounds and race regularly is important.

Exercise during training needs to emulate the stressors applied during racing for tissue to adapt to the type and magnitude of the load. In Chapter 3, trainers reported using high-intensity workouts, including galloping, trials, and racing, a median of two times per week (IQR: 1-3). Training programmes demonstrated a pattern and the specificity required for conditioning physiological and metabolic systems to the requirements of sprint racing. However, most of the trainers reported using a straight track at home to gallop dogs between races. Galloping around a bend increases the peak force on the legs compared to on a straight (Usherwood & Wilson, 2005). Specificity of training signals tissue to remodel in a fashion that will prepare the greyhound for the rigors of racing. The results from Chapter 4 agree with previous literature that most injuries that happen when racing on an oval track occur on a bend (Sicard et al., 1999). High-intensity training induces forces which prompt site specific adaptation of bone, however, the forces experienced by the limbs on a straight track are different to those encountered when sprinting around a bend. Evidence for the asymmetrical loading of the distal limb bones on a circular track is reported in the literature where fatigue fractures were prominent in the central tarsal bones and in the metacarpal bones of the right hind-limb (Muir et al., 1999; Johnson et al., 2000; Tomlin et al., 2000; Johnson et al., 2001; Thompson et al., 2012). Training needs to induce bone specific adaptation appropriate to the work required. Perhaps trainers could utilise trials at the racetracks more frequently to incorporate high-intensity training which conditions the limbs to the forces endured during racing. Like most greyhound races, Thoroughbred racehorses also race on an ovoid track and it has been demonstrated that racehorses trained by galloping around bends daily are less prone to stress fractures (Carrier et al., 1998).

The monitoring and recording of injuries in racing greyhounds in New Zealand relies on an injury reporting form where the veterinarian and Stipendiary Stewards can write as much, or as little, information as deemed necessary. There needs to be greater consistency and precision of injury reporting at tracks in New Zealand if progress in identifying injury risk factors and reducing incident rates is to be made. Currently, the injury reporting forms allow veterinarians to provide as much, or as little, information as they deem necessary. While improvements were made to the injury reporting in 2014, which was necessitated by an inquiry into the industry (Colgan et al., 2013), the current level of reporting hampered the precision of the data available. A standardised incident report form, such as the Australian Racing Incident Database online system utilised by both the galloping and harness racing codes in Australasia, needs to be implemented by GRNZ. Such structured reporting would provide greater accuracy and consistency of the reported injuries occurring on race-day and allow for future analysis of the racing data. Benchmarking and monitoring at every level - from monitoring injuries at a single track over time, to nation-wide injury monitoring, as well as track and regional comparisons is necessary to better define the incidence of injury and to identify the best and worst performing venues.

6.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The empirical findings in this study provide a basis for industry change and future research. The current racing system in New Zealand is operating within the biological constraints of the greyhounds with regards to the workload, racing patterns, age at racing start and career duration. As greyhounds age past the point of peak performance, they lose the ability to reach maximum speed and their prospects as racing stock reduce. In addition, the risk of injury increases with increasing age, which potentially limits the dogs' career duration. Ideally, when greyhounds finish racing, they are healthy and sound enough to be able to be rehomed as pets because they can make good companion animals.

The cross-sectional survey (Chapter 3) provided an insight to the typical training programme for greyhounds that were racing. Further research could expand on this knowledge to investigate musculoskeletal injuries occurring during training. Capture of dog-level data would require a prospective study to allow training details to be accurately recorded. Studies have reported that a greater number of musculoskeletal injuries and fatalities occur during training than racing in Thoroughbred horses (Johnson et al., 1994; Verheyen & Wood, 2004; Perkins et al., 2005). To the author's knowledge, no studies have quantified injuries sustained during training in racing greyhounds. Analysis of training data would allow information on the volume of high-intensity exercise and the incidence of injuries occurring during training to be gathered which in turn could be used to identify risk factors for injuries sustained during training and modifications to be made to reduce their impact.

A need remains to investigate the impact that racetrack may have on racing injuries. While it was hypothesised that the considerable variation in incidence rate and risk of musculoskeletal injuries across the different racetracks was due to data recording by different personnel and the identification of dogs that need to be examined by the veterinarian, differences in the track surface, starting box position, turn radius, camber of the tracks and lure arm distance have previously been identified as factors that contribute to the safety of racetracks (Iddon et al., 2014; Eager et al., 2017; Eager et al., 2018; Hayati et al., 2019; Hayati et al., 2020; Hossain et al., 2020). If the optimal method in which greyhound limbs interact with the track can be identified, this may help to reduce the rate of injuries occurring. In order to identify if the variable injury rates at different tracks were due to data recording practices or other factors, information on the number of greyhounds seen by the vet after their race as well as recording injuries obtained during racing should be collected. A concurrent change in these parameters would suggest that variation was due to the number of greyhounds subject to a veterinary examination, rather than track design factors.

6.4 CONCLUSIONS

The research undertaken in this thesis highlights the issues currently facing the greyhound racing industry in New Zealand. The work represents the first published research internationally to describe career patterns, training practices and identify risk factors for the most common racing injuries occurring on race day in greyhounds. Training programmes demonstrated high specificity and were designed to physiologically condition the dogs for the rigours involved with sprint racing. Racing injuries continue to undermine the health and welfare of greyhounds, despite advances in our understanding of their aetiology and the effect they have on the dogs. Both modifiable and unmodifiable risk factors for racing injuries were identified in this research. While injuries are an inherent risk with athletic endeavour, this thesis has demonstrated that most injuries sustained by racing greyhounds were due to high-speed galloping in top racing grades and interference with other dogs, which were factors associated with exposure time. For injury data to be used to drive industry change, the level of precision at which injuries are reported needs to be improved. Only when data are more thorough and robust, will the industry be able to rely on it for making decisions and providing scientific evidence for the success or failure of interventions aimed at protecting the welfare of the greyhound.

This thesis identified that the workload of racing greyhounds remained consistent throughout their racing careers and that the patterns of racing and training were homogeneous. The greyhound racing industry is currently working within the constraints of the greyhounds with regards to the workload, racing schedules, and career length. The results provide key data on the current industry practices and represent a valuable source of information for the industry.

REFERENCES

Bailey, C., Reid, S., Hodgson, D., & Rose, R. (1999). Factors associated with time until first race and career duration for Thoroughbred racehorses. *American Journal of Veterinary Research*, *60*(10), 1196-1200.

Beer, L. M. (2014). *A study of injuries in Victorian racing greyhounds 2006-2011* [Master's Thesis, The University of Melbourne]. Melbourne, Australia. http://hdl.handle.net/11343/42190.

Bhatt, V. S., Zaldívar-López, S., Harris, D. R., Couto, C. G., Wang, P. G., & Palmer, A. F. (2011). Structure of greyhound hemoglobin: origin of high oxygen affinity. *Acta Crystallographica Section D: Biological Crystallography*, *67*(5), 395-402.

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

Bolwell, C. F., Rogers, C. W., Gee, E. K., & Rosanowski, S. M. (2016b). Descriptive statistics and the pattern of horse racing in New Zealand. 2. Harness racing. *Animal Production Science*, *56*(1), 82-86.

Carrier, T. K., Estberg, L., Stover, S. M., Gardner, I., Johnson, B. J., Read, D. H., & Ardans, A. (1998). Association between long periods without high-speed workouts and risk of complete humeral or pelvic fracture in thoroughbred racehorses: 54 cases (1991-1994). *Journal of the American Veterinary Medical Association*, *212*(10), 1582-1587.

Colgan, B., Neil, C., & Foy, L. (2013). *New Zealand Greyhound Racing Association, Independant Welfare Review*. WHK.

Dobson, G. P., Parkhouse, W. S., Weber, J.-M., Stuttard, E., Harman, J., Snow, D. H., & Hochachka, P. W. (1988). Metabolic changes in skeletal muscle and blood of greyhounds during 800-m track sprint. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *255*(3), R513-R519.

Donald, D. E., Milburn, S. E., & Shepherd, J. T. (1964). Effect of cardiac denervation on the maximal capacity for exercise in the racing greyhound. *Journal of Applied Physiology*, *19*(5), 849-852.

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: a systematic review with meta-analysis. *Frontiers in Physiology*, *9*, 403.

Dykgraaf, S., Firth, E. C., Rogers, C. W., & Kawcak, C. E. (2008). Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *The Veterinary Journal*, *178*(1), 53-61.

Eager, D., Hayati, H., & Hossain, M. (2017). *Identifying optimal greyhound track design for greyhound safety and welfare. Phase I Report January 2016 to 31 December 2016*. University of Technology Sydney.

Eager, D., Hayati, H., Mahdavi, F., Hossain, M., Stephenson, R., & Thomas, N. (2018). *Identifying optimal greyhound track design for greyhound safety and welfare-Phase II-Progress Report-1 January 2016 to 31 December 2017*. University of Technology Sydney.

Firth, E. C., Rogers, C. W., van Weeren, P. R., Barneveld, A., McIlwraith, C. W., Kawcak, C. E., Goodship, A. E., & Smith, R. K. (2011). Mild exercise early in life produces changes in bone size and strength but not density in proximal phalangeal, third metacarpal and third carpal bones of foals. *The Veterinary Journal*, *190*(3), 383-389.

Greyhound Racing New Zealand. (2017). *Regulations of the New Zealand Greyhound Racing Association Incorporated including the Rules of Racing*. New Zealand Greyhound Racing Association. https://www.grnz.co.nz/Files/Rules%20of%20Racing/J001839%20MASTER%20GRNZ%20Rules%20of%20Racing%20effective%201%20August%202018%20(clean)%20-%2030...%20(1).pdf

Gunningham, N., Kagan, R. A., & Thornton, D. (2004). Social license and environmental protection: why businesses go beyond compliance. *Law & Social Inquiry*, *29*(2), 307-341.

Guy, P., & Snow, D. (1981). Skeletal muscle fibre composition in the dog and its relationship to athletic ability. *Research in Veterinary Science*, *31*(2), 244-248.

Hayati, H., Eager, D., Peham, C., & Qi, Y. (2020). Dynamic behaviour of high performance of sand surfaces used in the sports industry. *Vibration*, *3*(4), 410-424.

Hayati, H., Eager, D., & Walker, P. (2019). The effects of surface compliance on greyhound galloping dynamics. *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, *233*(4), 1033-1043.

Hill, R. C., Fox, L. E., Lewis, D. D., Beale, K. M., Nachreiner, R. F., Scott, K. C., Sundstrom, D. A., Jones, G. L., & Butterwick, R. F. (2001). Effects of racing and training on serum thyroid hormone concentrations in racing Greyhounds. *American Journal of Veterinary Research*, *62*(12), 1969-1972.

Hossain, M. I., Eager, D., & Walker, P. D. (2020). Greyhound racing ideal trajectory path generation for straight to bend based on jerk rate minimization. *Scientific Reports*, *10*(1), 1-15.

Iddon, J., Lockyer, R., & Frean, S. (2014). The effect of season and track condition on injury rate in racing greyhounds. *Journal of Small Animal Practice, 55*(8), 399-404.

Ilkiw, J., Davis, P., & Church, D. (1989). Hematologic, biochemical, blood-gas, and acid-base values in greyhounds before and after exercise. *American Journal of Veterinary Research*, *50*(4), 583-586.

Johnson, B., Stover, S. M., Daft, B. M., Kinde, H., Read, D., Barr, B., Anderson, M., Moore, J., Woods, L., & Stoltz, J. (1994). Causes of death in racehorses over a 2 year period. *Equine Veterinary Journal*, *26*(4), 327-330.

Johnson, K., Muir, P., Nicoll, R., & Roush, J. (2000). Asymmetric adaptive modeling of central tarsal bones in racing greyhounds. *Bone*, *27*(2), 257-263.

Johnson, K. A., Skinner, G. A., & Muir, P. (2001). Site-specific adaptive remodeling of Greyhound metacarpal cortical bone subjected to asymmetrical cyclic loading. *American Journal of Veterinary Research*, *62*(5), 787-793.

Kesl, L. D. (1993). *The effects of sprint training regimens and sodium bicarbonate loading on muscle glycolysis, lactate accumulation, acid-base balance, and performance in the racing greyhound* [Doctoral dissertation, Iowa State University]. Retrospective Theses and Dissertations. 10666. https://lib.dr.iastate.edu/rtd/10666/

Lonsdale, R. A., Labuc, R. H., & Robertson, I. D. (1998). Echocardiographic parameters in training compared with non-training Greyhounds. *Veterinary Radiology & Ultrasound*, *39*(4), 325-330.

Muir, P., Johnson, K., & Ruaux-Mason, C. (1999). In vivo matrix microdamage in a naturally occurring canine fatigue fracture. *Bone*, *25*(5), 571-576.

Parkin, T. D. (2008). Epidemiology of racetrack injuries in racehorses. *Veterinary Clinics of North America: Equine Practice, 24*(1), 1-19.

Pellegrino, F. J., Risso, A., Vaquero, P. G., & Corrada, Y. A. (2018). Physiological parameter values in greyhounds before and after high-intensity exercise. *Open Veterinary Journal*, *8*(1), 64-67.

Perkins, N., Reid, S., & Morris, R. (2005). Profiling the New Zealand Thoroughbred racing industry. 2. Conditions interfering with training and racing. *New Zealand Veterinary Journal*, *53*(1), 69-76.

Rippe, J. M., Pape, L. A., Alpert, J. S., Ockene, I. S., Paraskos, J. A., Kotilainen, P., Anas, J., & Webster, W. (1982). Studies of systolic mechanics and diastolic behavior of the left ventricle in the trained racing greyhound. *Basic Research in Cardiology*, *77*(6), 619-644.

Rose, R., & Bloomberg, M. (1989). Responses to sprint exercise in the greyhound: effects on haematology, serum biochemistry and muscle metabolites. *Research in Veterinary Science, 47*(2), 212-218.

Sicard, G., Short, K., & Manley, P. (1999). A survey of injuries at five greyhound racing tracks. *Journal of Small Animal Practice*, *40*(9), 428-432.

Stevenson, M., Stafford, K., & Cave, N. (2009). Risk factors for injury in New Zealand racing greyhounds: *A report prepared for the New Zealand Racing Greyhound Association.* Massey University.

Täubert, H., Agena, D., & Simianer, H. (2007). Genetic analysis of racing performance in Irish greyhounds. *Journal of Animal Breeding and Genetics*, *124*(3), 117-123.

Thompson, D., Cave, N., Bridges, J., Reuvers, K., Owen, M., & Firth, E. (2012). Bone volume and regional density of the central tarsal bone detected using computed tomography in a cross-sectional study of adult racing greyhounds. *New Zealand Veterinary Journal*, *60*(5), 278-284.

Tomlin, J., Lawes, T., Blunn, G., Goodship, A., & Muir, P. (2000). Fractographic examination of racing greyhound central (navicular) tarsal bone failure surfaces using scanning electron microscopy. *Calcified Tissue International*, *67*(3), 260-266.

Usherwood, J. R., & Wilson, A. M. (2005). No force limit on greyhound sprint speed. *Nature*, *438*(7069), 753-754.

Van Weeren, P., Firth, E., Brommer, H., Hyttinen, M., Helminen, H., Rogers, C., Degroot, J., & Brama, P. (2008). Early exercise advances the maturation of glycosaminoglycans and collagen in the extracellular matrix of articular cartilage in the horse. *Equine Veterinary Journal*, *40*(2), 128-135.

Velie, B., Knight, P., Thomson, P., Wade, C., & Hamilton, N. (2013). The association of age at first start with career length in the Australian Thoroughbred racehorse population. *Equine Veterinary Journal*, *45*(4), 410-413.

Verheyen, K., & Wood, J. (2004). Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine Veterinary Journal*, *36*(2), 167-173.

Warden, S. J., Fuchs, R. K., Castillo, A. B., Nelson, I. R., & Turner, C. H. (2007). Exercise when young provides lifelong benefits to bone structure and strength. *Journal of Bone and Mineral Research*, *22*(2), 251-259.

Warden, S. J., Roosa, S. M. M., Kersh, M. E., Hurd, A. L., Fleisig, G. S., Pandy, M. G., & Fuchs, R. K. (2014). Physical activity when young provides lifelong benefits to cortical bone size and strength in men. *Proceedings of the National Academy of Sciences*, 111(14), 5337-5342.

Appendices

APPENDIX 1

This appendix includes a copy of the survey used to collect data on training practices of racing greyhounds in New Zealand.

Training survey of New Zealand racing greyhounds

Massey University Doctoral student, Anna Palmer, and supervisors Dr Charlotte Bolwell, Associate Professor Chris Roger, Professor Kevin Stafford and Dr Arnon Gal are conducting a survey to understand the training of Greyhounds in New Zealand.

1. This survey contains questions about the greyhounds you train. Answers are generalised so please consider a **typical greyhound** when completing the questions.

2. Questions require you to either tick the boxes, or provide details in the form of a written answer.

3. Please consider all options before indicating the most appropriate response to each and every question.

4. This survey should only take **15 minutes** to complete.

5. All responses are completely **confidential**. Data will be used for research purposes only.

6. By completing this survey, you are giving your consent for the information you give to be used as part of this research.

7. Please return the survey by post as soon as possible and before **4th October** 2019.

Thank you for your assistance!

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

SCHOOL OF VETERINARY SCIENCE

Greyhound training survey

How many dogs are you currently training TODAY? ☐☐☐

Which type of training license do you hold?

- Public ☐
- Owner/Trainer ☐

What is your age?

- ≤20 years ☐
- 21-30 years ☐
- 31-40 years ☐
- 41-50 years ☐
- 51-60 years ☐
- 61-70 years ☐
- 71-80 years ☐
- 81≥ years ☐

What is your gender?

- Male ☐
- Female ☐

How many years have you been training greyhounds? ☐☐

What facilities do you use to train your dogs? Please fill out the following table by circling the appropriate answer or providing details where applicable.

Run or slipping track	Y / N	Distance of run:	Straight / Curved	Flat / Hill
Exercise paddock	Y / N	Size (h):		
Circular training track	Y / N	Diameter:		
Bull Ring	Y / N	Diameter:		
Local race track	Y / N	Track name:		
Beach	Y / N			
Treadmill	Y / N			
Starting box(es)	Y / N			
Other facilities (Please specify)				

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND
SCHOOL OF VETERINARY SCIENCE

Section 1 – Training before dogs begin racing

If you prepare young dogs for racing or train dogs before they begin racing, please answer the questions BELOW.

If you have only trained dogs that are in race work, please go to Section 2 (page 6).

What is the primary reason for deciding when to register a dog for racing? (Select one)

- Overall appearance of the dog (looks fit and healthy) ☐
- Capable of meeting time milestones ☐
- Been in training for an appropriate number of weeks (please specify) ☐ ____weeks
- Owner decision ☐
- All dogs in training are registered for racing ☐
- Age of the dog ☐
- Other (please specify) ______________________________

Do your dogs follow a standard training programme up to their first race?

- Standard training programme for all dogs ☐
- Similar training programme with minor changes for each dog ☐
- Different training programme for each dog ☐

At what age (months) do dogs typically begin training? [|] months

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND
SCHOOL OF VETERINARY SCIENCE

Typically, from entering training, how many weeks does it take for a dog to reach the following milestones? (Please state n/a if not applicable to your programme)

Milestone	Number of weeks from entering training
Learning to chase	
Fast work	
Box training	
Hand slip on track or partial trials	
Full trials before a break	
Full trials after a break	
Qualifying trial	
First Race	

Do your young dogs have a break during the breaking in process?

No ☐

Yes – please state the length of break: ____________________

When or at what stage does this occur? ____________________

Do you utilise trials (not qualifying trials) as part of a dog's training programme?

No ☐

Yes – Primary reason:

- to educate the dog ☐
- to improve fitness ☐
- for another reason: please state: ____________________

How many full trials would a dog typically have before its qualifying trial? ☐☐

What is the primary reason for deciding when a dog is ready for a qualifying trial? (Select one)

Overall appearance of the dog (looks fit and healthy)	☐	
Capable of meeting time milestones	☐	
Been in training for an appropriate number of weeks (please specify)	☐	____weeks
Owner decision	☐	
All dogs in training complete a qualifying trial	☐	
Age of the dog	☐	

Other (please specify) ____

Section 2 – Training that occurs while the dogs are racing

The following question relates to the typical weekly training programme for a dog. The table below provides an example of how to complete this question.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Type of training For example: Gallop Walk Race Play Free exercise Other (Please specify)	Racing		Walk Free exercise	Gallop	Free exercise		
Racing (please tick)	✓						
Day off (please tick)		✓				✓	✓
Location For example: Race Track Run Paddock Beach Bull Ring Other (Please specify)	Race Track		Walk = Treadmill Free exercise = exercise paddock	Run	Paddock		
Distance	457m		Walk = 2km Free ex. = N/A	200m	N/A		
Frequency i.e. number of times activity performed	1		Walk = 1 Free ex. = 1 morning & 1 night	1	2 (1 Morning and 1 Night)		
Duration	20 seconds		Walk = 20mins Free ex. = 5 mins each	15 seconds	20 minutes each		
Other comments							

EXAMPLE

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

SCHOOL OF VETERINARY SCIENCE

Using the following table, please outline the <u>typical</u> weekly training programme for a dog, in full racing fitness, based around race-day(s). Please see the previous table for an example:

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Type of training For example: Gallop Walk Race Play Free exercise Other (Please specify)							
Racing (please tick)							
Day off (please tick)							
Location For example: Race Track Run Paddock Beach Bull Ring Other (Please specify)							
Distance							
Frequency i.e. number of times activity performed							
Duration							
Other comments							

Does your weekly training programme differ for sprinting dogs, middle distance dogs or staying dogs?

Yes No

If yes, please briefly describe the changes you make to the training programme and why you make these changes?

Do you make changes to a dog's training programme in the 48 hours before a race?

Yes No

If yes, please briefly describe the changes you make and explain why you make these changes?

What method do you use to record training sessions?

- I do not record training sessions ☐
- I record training sessions on paper or in a diary ☐
- I record training sessions in an electronic format or on a spreadsheet ☐
- Other (please specify) ______________________________

If you record training sessions, which of the following do you record?

- Time ☐
- Type of work ☐
- Frequency of work ☐
- Distance ☐
- Other (please specify) ______________________________

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND
SCHOOL OF VETERINARY SCIENCE

Thank you

...for taking the time to participate in this survey. We appreciate your time and effort!

Please **post** the survey to Anna Palmer in the **pre-paid envelope** attached.

APPENDIX 2

Incidence of injuries experienced by racing greyhounds in New Zealand as reported by on-track veterinarians and Stipendiary Stewards (September 2014 and June 2019), stratified by sex, country, race year, racetrack, race number at meeting, starting box number, race distance type, race grade, and age.

		Number of events		Incidence per 1,000 starts (95% CI)	
Variable	**n starts**	**Injury[a]**	**Fatality**	**Injury[a]**	**Fatality**
Sex					
Dog	124,929	2,374	185	19.0 (18.3-19.8)	1.5 (1.3-1.7)
Bitch	88,701	1,726	86	19.5 (18.6-20.4)	1.0 (0.8-1.2)
Country					
New Zealand	160,691	2,917	186	18.2 (17.5-18.8)	1.2 (1.0-1.3)
Australia	52,939	1,183	85	22.3 (21.1-23.6)	1.6 (1.3-2.0)
Race year					
2014[b]	38,125	774	58	20.3 (18.9-21.8)	1.5 (1.2-2.0)
2015	44,076	981	60	22.3 (20.9-23.7)	1.4 (1.0-1.8)
2016	44,365	706	47	15.9 (14.8-17.1)	1.1 (0.8-1.4)
2017	46,382	799	57	17.2 (16.1-18.4)	1.2 (0.9-1.6)
2018[b]	40,682	840	49	20.6 (19.3-22.1)	1.2 (0.9-1.6)
Racetrack					
Track A	27,476	722	37	26.3 (24.4-28.2)	1.3 (0.9-1.9)
Track B	20,631	316	21	15.3 (13.7-17.1)	1.0 (0.6-1.6)
Track C	62,735	761	92	12.1 (11.3-13.0)	1.5 (1.2-1.8)
Track D	13,064	130	13	10.0 (8.3-11.8)	1.0 (0.5-1.7)
Track E	12,831	141	10	11.0 (9.3-12.9)	0.8 (0.4-1.4)
Track F	25,023	716	23	28.6 (26.6-30.8)	0.9 (0.6-1.4)
Track G	51,870	1,314	75	25.3 (24.0-26.7)	1.4 (1.1-1.8)
Race number at meeting					
1	16,895	387	24	22.9 (20.7-25.3)	1.4 (0.9-2.1)
2	16,884	350	21	20.7 (18.6-23.0)	1.2 (0.8-1.9)
3	16,841	345	16	20.5 (18.4-22.7)	1.0 (0.5-1.5)
4	16,823	333	21	19.8 (17.7-22.0)	1.2 (0.8-1.9)
5	16,831	335	25	19.9 (17.8-22.1)	1.5 (1.0-2.2)
6	16,840	347	20	20.6 (18.5-22.9)	1.2 (0.7-1.8)
7	16,850	352	18	20.9 (18.8-23.2)	1.1 (0.6-1.7)
8	16,836	287	20	17.0 (15.1-19.1)	1.2 (0.7-1.8)
9	16,711	295	13	17.7 (15.7-19.8)	0.8 (0.4-1.3)
10	16,720	302	29	18.1 (16.1-20.2)	1.7 (1.2-2.5)
11	16,424	300	24	18.3 (16.3-20.4)	1.5 (0.9-2.2)
12	16,027	269	26	16.8 (14.9-18.9)	1.6 (1.1-2.4)
13	5,783	94	5	16.3 (13.2-19.9)	0.9 (0.3-2.0)
14	3,877	59	7	15.2 (11.6-19.6)	1.8 (0.7-3.7)
15-23	3,288	45	2	13.7 (10.0-18.3)	0.6 (0.07-2.2)

Starting box number					
1	26,786	489	20	18.3 (16.7-19.9)	0.7 (0.5-1.2)
2	26,740	544	27	20.3 (18.7-22.1)	1.0 (0.7-1.5)
3	26,675	552	45	20.7 (19.0-22.5)	1.7 (1.2-2.3)
4	26,701	507	29	19.0 (17.4-20.7)	1.1 (0.7-1.6)
5	26,620	513	40	19.3 (17.7-21.0)	1.5 (1.1-2.0)
6	26,712	558	38	20.9 (19.2-22.7)	1.4 (1.0-2.0)
7	26,714	474	26	17.7 (16.2-19.4)	1.0 (0.6-1.4)
8	26,682	463	46	17.4 (15.8-19.0)	1.7 (1.3-2.3)
Race type					
Sprint	139,505	2,746	201	19.7 (19.0-20.4)	1.4 (1.2-1.7)
Middle	70,087	1,291	65	18.4 (17.4-19.4)	0.9 (0.7-1.2)
Distance	4,038	63	5	15.6 (12.0-19.9)	1.2 (0.4-2.9)
Race grade					
C0	29,792	556	32	18.7 (17.2-20.3)	1.1 (0.7-1.5)
C1	75,464	1,470	102	19.5 (18.5-20.5)	1.4 (1.1-1.6)
C2	37,638	758	46	20.1 (18.7-21.6)	1.2 (0.9-1.6)
C3	25,358	496	36	19.6 (17.9-21.3)	1.4 (1.0-2.0)
C4	23,599	432	26	18.3 (16.6-20.1)	1.1 (0.7-1.6)
C5	13,700	254	21	18.5 (16.3-20.9)	1.5 (0.9-2.3)
Other	8,079	134	8	16.6 (13.9-19.6)	1.0 (0.4-2.0)
Age at time of injury (months) [c]					
14-26	59,746	861	53	14.6 (13.7-15.6)	0.9 (0.7-1.2)
27-32	52,241	961	61	18.7 (17.6-20.0)	1.2 (0.9-1.5)
33-39	49,697	1,000	71	20.5 (19.3-21.8)	1.5 (1.1-1.8)
40-79	51,088	1,266	85	25.4 (24.0-26.8)	1.7 (1.4-2.1)

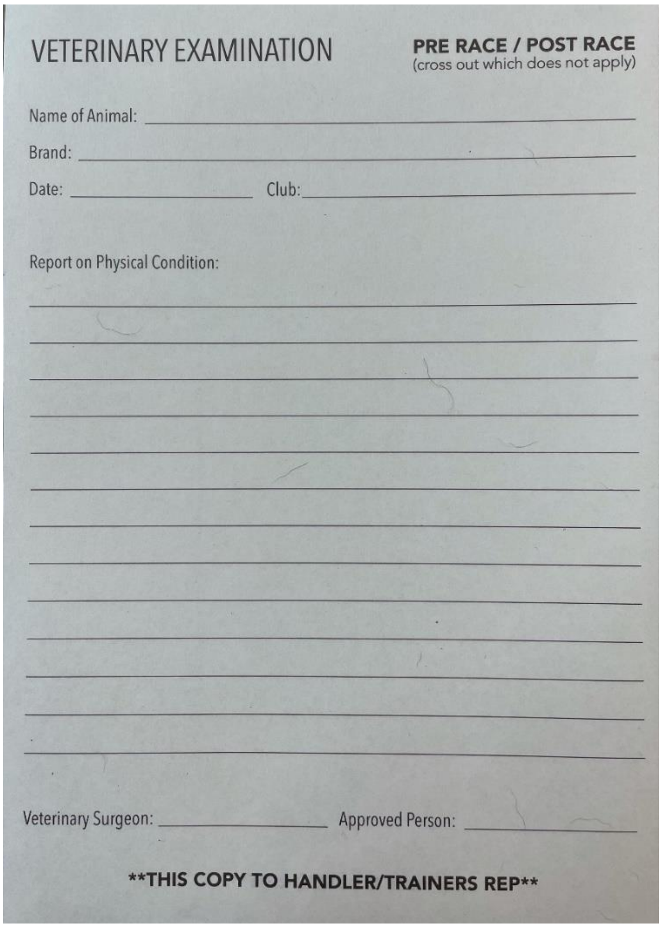
[a] Injuries including fatalities

[b] Data were not available for full racing seasons

[c] Age not available for 109 greyhounds across 858 racing starts; age data n= 212,772

APPENDIX 3

Standardised injury reporting form used by on-track veterinarians for recording details of injuries sustained by greyhounds at the racetrack.



VETERINARY EXAMINATION

PRE RACE / POST RACE
(cross out which does not apply)

Name of Animal: ____________________

Brand: ____________________

Date: __________ Club: __________

Report on Physical Condition:

Veterinary Surgeon: __________ Approved Person: __________

****THIS COPY TO HANDLER/TRAINERS REP****

APPENDIX 4

Results of univariable logistic regression screening of variables associated with fractures in racing greyhounds in New Zealand.

Variable	**Category**	**Coefficient**	**SE[a]**	**Unadjusted OR[b]**	**95% CI**		**p-value[c]**	**LRS[d] p-value**
					Lower	**Upper**		
Sex								0.05
	Dog	Ref						
	Bitch	-0.19	0.10	0.83	0.68	1.00	0.05	
Country of origin								0.00
	New Zealand	Ref						
	Australia	0.46	0.10	1.59	1.31	1.93	0.00	
Race age (months)								0.00
	14-25	Ref						
	26-31	0.35	0.14	1.42	1.07	1.87	0.02	
	32-38	0.56	0.14	1.76	1.33	2.31	0.00	
	39-77	0.58	0.14	1.79	1.36	2.35	0.00	
Days since previous race								0.01
	<7	Ref						
	7	0.16	0.12	1.17	0.94	1.47	0.16	
	>7	0.33	0.11	1.40	1.12	1.74	0.00	
Race type								0.49
	Sprint	Ref						
	Middle	-0.09	0.10	0.91	0.75	1.11	0.36	
	Distance	0.21	0.31	1.24	0.68	2.26	0.49	

Race grade								0.00
	Class 1	Ref						
	Class 0	-0.19	0.16	0.83	0.60	1.14	0.24	
	Class 2	0.06	0.14	1.06	0.80	1.41	0.67	
	Class 3	0.24	0.15	1.28	0.94	1.73	0.11	
	Class 4	0.35	0.17	1.41	1.02	1.96	0.04	
	Class 5	0.59	0.14	1.80	1.36	2.39	0.00	
	Other	-0.06	0.30	0.94	0.52	1.69	0.83	
Racetrack								0.01
	Track A	Ref						
	Track B	-0.52	0.26	0.60	0.36	0.99	0.05	
	Track C	0.28	0.14	1.33	1.01	1.75	0.04	
	Track D	-0.01	0.13	0.99	0.77	1.26	0.92	
	Track E	-0.20	0.18	0.82	0.57	1.18	0.28	
	Track F	-0.32	0.23	0.72	0.46	1.14	0.17	
	Track G	-0.20	0.17	0.82	0.58	1.14	0.23	
Starting box								0.08
	1	Ref						
	2	0.41	0.21	1.51	1.00	2.29	0.05	
	3	0.52	0.21	1.69	1.12	2.53	0.01	
	4	0.42	0.21	1.52	1.00	2.30	0.05	
	5	0.51	0.21	1.66	1.10	2.50	0.02	
	6	0.45	0.21	1.57	1.04	2.38	0.03	
	7	0.42	0.21	1.52	1.00	2.30	0.05	
	8	0.67	0.20	1.95	1.31	2.90	0.00	

Season								0.16
	Winter	Ref						
	Spring	0.16	0.14	1.17	0.90	1.53	0.25	
	Summer	0.19	0.13	1.20	0.93	1.57	0.17	
	Autumn	0.29	0.13	1.34	1.04	1.74	0.03	
Race year								0.61
	2018/2019	Ref						
	2019/2020	-0.17	0.15	0.84	0.63	1.13	0.25	
	2017/2018	-0.18	0.15	0.83	0.63	1.11	0.21	
	2016/2017	-0.08	0.15	0.92	0.69	1.22	0.56	
	2015/2016	-0.01	0.15	0.99	0.74	1.34	0.97	
	2014/2015	0.10	0.21	1.10	0.73	1.66	0.64	

[a] SE: Standard error
[b] OR: Odds ratio
[c] Wald p-value
[d] LRS p-value: Likelihood ratio statistic p-value

APPENDIX 5

Results of univariable logistic regression screening of variables associated with laceration injuries in racing greyhounds in New Zealand.

Variable	**Category**	**Coefficient**	**SE[a]**	**Unadjusted OR[b]**	**95% CI**		**p-value[c]**	**LRS[d] p-value**
					Lower	**Upper**		
Sex								0.08
	Dog	Ref						
	Bitch	-0.14	0.08	0.87	0.74	1.02	0.08	
Country of origin								
	New Zealand	Ref						0.00
	Australia	0.40	0.09	1.49	1.26	1.76	0.00	
Career start number								0.22
	1-13	Ref						
	14-28	-0.04	0.11	0.96	0.77	1.20	0.71	
	29-51	-0.11	0.11	0.89	0.72	1.12	0.33	
	52-231	0.12	0.11	1.12	0.91	1.39	0.27	
Days since previous race								0.43
	<7	Ref						
	7	-0.12	0.09	0.89	0.74	1.07	0.20	
	>7	-0.08	0.10	0.93	0.77	1.12	0.42	
Race type								0.21
	Sprint	Ref						
	Middle	-0.07	0.09	0.94	0.79	1.11	0.44	
	Distance	0.38	0.24	1.47	0.91	2.35	0.11	

Race grade								0.08
	Class 1	Ref						
	Class 0	0.03	0.13	1.03	0.81	1.32	0.79	
	Class 2	0.15	0.12	1.16	0.93	1.46	0.19	
	Class 3	0.21	0.13	1.23	0.95	1.59	0.11	
	Class 4	-0.11	0.17	0.90	0.65	1.24	0.52	
	Class 5	0.36	0.13	1.43	1.11	1.85	0.01	
	Other	0.03	0.24	1.03	0.64	1.65	0.91	
Racetrack								0.00
	Track A	Ref						
	Track B	-0.21	0.20	0.81	0.54	1.21	0.30	
	Track C	0.49	0.12	1.64	1.30	2.07	0.00	
	Track D	0.17	0.11	1.19	0.96	1.47	0.11	
	Track E	0.06	0.15	1.06	0.79	1.43	0.70	
	Track F	-0.62	0.24	0.54	0.34	0.86	0.01	
	Track G	0.12	0.14	1.12	0.86	1.47	0.39	
Starting box								0.22
	1	Ref						
	2	0.05	0.17	1.06	0.76	1.46	0.74	
	3	0.21	0.16	1.23	0.90	1.69	0.19	
	4	0.20	0.16	1.23	0.90	1.68	0.20	
	5	0.15	0.16	1.16	0.85	1.60	0.35	
	6	0.33	0.16	1.39	1.02	1.88	0.04	
	7	0.06	0.17	1.06	0.76	1.46	0.74	
	8	-0.07	0.17	0.93	0.67	1.30	0.68	

Season								0.39
	Winter	Ref						
	Spring	0.12	0.11	1.13	0.91	1.40	0.26	
	Summer	-0.07	0.11	0.93	0.75	1.16	0.53	
	Autumn	0.02	0.11	1.02	0.82	1.27	0.85	
Race year								0.12
	2018/2019	Ref						
	2019/2020	0.18	0.12	1.19	0.94	1.52	0.16	
	2017/2018	-0.04	0.13	0.97	0.75	1.24	0.78	
	2016/2017	-0.10	0.13	0.90	0.70	1.17	0.44	
	2015/2016	0.19	0.13	1.21	0.94	1.56	0.15	
	2014/2015	0.21	0.18	1.24	0.87	1.77	0.24	

[a] SE: Standard error

[b] OR: Odds ratio

[c] Wald p-value

[d] LRS p-value: Likelihood ratio statistic p-value

APPENDIX 6

Results of univariable logistic regression screening of variables associated with soft-tissue injury in racing greyhounds in New Zealand.

Variable	**Category**	**Coefficient**	**SE[a]**	**Unadjusted OR[b]**	**95% CI**		**p-value[c]**	**LRS[d] p-value**
					Lower	**Upper**		
Sex								0.04
	Dog	Ref						
	Bitch	0.08	0.04	1.08	1.00	1.16	0.04	
Country of origin								0.02
	New Zealand	Ref						
	Australia	0.10	0.04	1.10	1.01	1.19	0.02	
Race age (months)								0.00
	14-25	Ref						
	26-31	0.16	0.05	1.17	1.05	1.30	0.00	
	32-38	0.35	0.05	1.42	1.27	1.58	0.00	
	39-77	0.59	0.05	1.80	1.63	1.99	0.00	
Days since previous race								0.00
	<7	Ref						
	7	-0.10	0.04	0.90	0.83	0.99	0.02	
	>7	0.11	0.04	1.11	1.02	1.21	0.01	
Race type								0.00
	Sprint	Ref						
	Middle	-0.12	0.04	0.89	0.82	0.96	0.00	
	Distance	-0.21	0.15	0.81	0.61	1.07	0.14	

Race grade								0.00
	Class 1	Ref						
	Class 0	-0.04	0.06	0.96	0.86	1.07	0.44	
	Class 2	0.09	0.05	1.10	0.99	1.22	0.07	
	Class 3	-0.03	0.06	0.97	0.86	1.09	0.59	
	Class 4	-0.04	0.07	0.96	0.84	1.11	0.61	
	Class 5	-0.17	0.07	0.84	0.74	0.96	0.01	
	Other	-0.28	0.12	0.76	0.60	0.96	0.02	
Racetrack								0.00
	Track A	Ref						
	Track B	-0.30	0.13	0.74	0.57	0.96	0.02	
	Track C	0.96	0.07	2.61	2.29	2.97	0.00	
	Track D	1.21	0.06	3.36	3.01	3.75	0.00	
	Track E	0.52	0.08	1.68	1.43	1.97	0.00	
	Track F	-0.14	0.12	0.87	0.68	1.11	0.27	
	Track G	1.33	0.06	3.79	3.36	4.29	0.00	
Starting box								0.11
	1	Ref						
	2	0.05	0.07	1.05	0.91	1.21	0.48	
	3	0.03	0.07	1.03	0.90	1.19	0.64	
	4	0.02	0.07	1.02	0.89	1.17	0.77	
	5	-0.04	0.07	0.97	0.84	1.11	0.63	
	6	-0.02	0.07	0.98	0.85	1.13	0.80	
	7	-0.11	0.07	0.89	0.77	1.03	0.12	
	8	-0.14	0.07	0.87	0.75	1.01	0.07	

Season								
	Winter	Ref						0.08
	Spring	-0.05	0.05	0.95	0.86	1.05	0.33	
	Summer	-0.04	0.05	0.96	0.87	1.06	0.46	
	Autumn	-0.13	0.05	0.88	0.79	0.97	0.01	
Race year								0.00
	2018/2019	Ref						
	2019/2020	0.18	0.05	1.19	1.08	1.32	0.00	
	2017/2018	-0.32	0.06	0.72	0.65	0.81	0.00	
	2016/2017	-0.47	0.06	0.63	0.55	0.71	0.00	
	2015/2016	-0.12	0.06	0.89	0.79	1.00	0.05	
	2014/2015	-0.44	0.10	0.64	0.53	0.78	0.00	

[a] SE: Standard error

[b] OR: Odds ratio

[c] Wald p-value

[d] LRS p-value: Likelihood ratio statistic p-value

APPENDIX 7

Statements of contribution to doctoral thesis containing publications.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Anna Palmer
Name and title of main supervisor:	Professor Chris Rogers
In which chapter is the manuscript/published work?	Chapter 2
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:
The candidate conceptualised the study, curated the data, conducted all formal analysis, and wrote the original draft. She was also involved in the interpretation of results and production of the manuscript.

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:
  Palmer, A. L., Bolwell, C. F., Stafford, K. J., Gal, A., & Rogers, C. W. (2020). Patterns of Racing and Career Duration of Racing Greyhounds in New Zealand. Animals, 10(5), 796. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ani10050796

- ( ) **The manuscript is currently under review for publication**

  Please provide the name of the journal:

- ( ) **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	 Digitally signed by Anna Palmer Date: 2023.11.06 17:52:51 +13'00'	Main supervisor's signature:	Prof Chris Rogers

This form should be placed at the beginning of each relevant thesis chapter.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Anna Palmer
Name and title of main supervisor:	Professor Chris Rogers
In which chapter is the manuscript/published work?	Chapter 3
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate conceptualised the study, curated the data, conducted all formal analysis, and wrote the original draft. She was also involved in the design of the survey, interpretation of results and production of the manuscript.

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:

Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., Cochrane, D. J., & Bolwell, C. F. (2020). Cross-Sectional Survey of the Training Practices of Racing Greyhounds in New Zealand. Animals, 10(11), 2032. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ani10112032

( ) The manuscript is currently under review for publication

Please provide the name of the journal:

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Student's signature:	Digitally signed by Anna Palmer Date: 2023.11.06 22:43:56 +13'00'	Main supervisor's signature:	Prof Chris Rogers

This form should be placed at the beginning of each relevant thesis chapter.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Anna Palmer
Name and title of main supervisor:	Professor Chris Rogers
In which chapter is the manuscript/published work?	Chapter 4
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:
The candidate conceptualised the study, curated the data, conducted all formal analysis, and wrote the original draft. She was also involved in the interpretation of results and production of the manuscript.

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:
Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., & Bolwell, C. F. (2021). A Retrospective Descriptive Analysis of Race-Day Injuries of Greyhounds in New Zealand. Australian Veterinary Journal, 99(6), 255-262. Retrieved from https://doi.org/10.1111/avj.13064

( ) **The manuscript is currently under review for publication**

Please provide the name of the journal:

( ) **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Digitally signed by Anna Palmer Date: 2023.11.06 22:48:10 +13'00'	Main supervisor's signature:	Prof Chris Rogers Digitally signed by Prof Chris Rogers Date: 2023.11.08 18:28:24 +13'00'

This form should be placed at the beginning of each relevant thesis chapter.

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Anna Palmer
Name and title of main supervisor:	Professor Chris Rogers
In which chapter is the manuscript/published work?	Chapter 5
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:
The candidate conceptualised the study, curated the data, conducted formal data analysis, and wrote the original draft. She was also involved in the interpretation of results and production of the manuscript.

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:
Palmer, A. L., Rogers, C. W., Stafford, K. J., Gal, A., & Bolwell, C. F. (2021). Risk-factors for soft-tissue injuries, lacerations and fractures during racing in greyhounds in New Zealand. Frontiers in Veterinary Science, 8, 737146. Retrieved from https://doi.org/10.3389/fvets.2021.737146

( ) **The manuscript is currently under review for publication**

Please provide the name of the journal:

( ) **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Digitally signed by Anna Palmer Date: 2023.11.06 22:50:15 +13'00'	Main supervisor's signature:	Prof Chris Rogers

This form should be placed at the beginning of each relevant thesis chapter.